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**Yokoyama et al.**

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(54) **INK JET HEAD AND MANUFACTURING METHOD OF THE SAME**

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(51) **Int. Cl.**

| | |
|---|---|
| ***B41J 2/015*** | (2006.01) |
| ***B41J 2/045*** | (2006.01) |
| ***B41J 2/14*** | (2006.01) |
| ***B41J 2/16*** | (2006.01) |

(52) **U.S. Cl.**

CPC .............. ***B41J 2/045*** (2013.01); ***B41J 2/14233*** (2013.01); ***B41J 2/161*** (2013.01); ***B41J 2/1623*** (2013.01); ***B41J 2/1628*** (2013.01); ***B41J 2/1629*** (2013.01); ***B41J 2/1631*** (2013.01); ***B41J 2/1632*** (2013.01); ***B41J 2/1642*** (2013.01); ***B41J 2/1643*** (2013.01); ***B41J 2/1645*** (2013.01); ***B41J 2/1646*** (2013.01); *B41J 2002/1437* (2013.01); *Y10T 29/42* (2015.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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*Primary Examiner* — Erica Lin

(74) *Attorney, Agent, or Firm* — Patterson & Sheridan, LLP

(57) **ABSTRACT**

An ink jet head includes: a vibration plates having a plurality of openings of a first diameter; ink pressure chambers, each arranged on one surface of the corresponding vibration plate; first electrodes, each formed on the other surface of the vibration plate; a plurality of piezoelectric layers, each portion of which is formed on a first electrode such that it surrounds the opening and that, when a driving voltage is applied, deforms the vibration plate to expand or contract the ink pressure chamber; second electrodes formed on each piezoelectric layer; a protective layer which is at least formed on the vibration plate and the second electrode and has a nozzle for ejecting the ink having a diameter smaller than the first diameter extending therethrough and through the opening; and an ink-feeding mechanism that feeds the ink into the ink pressure chambers.

**10 Claims, 19 Drawing Sheets**

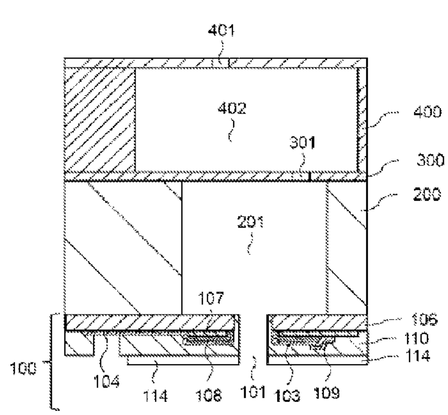

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FIG. 1

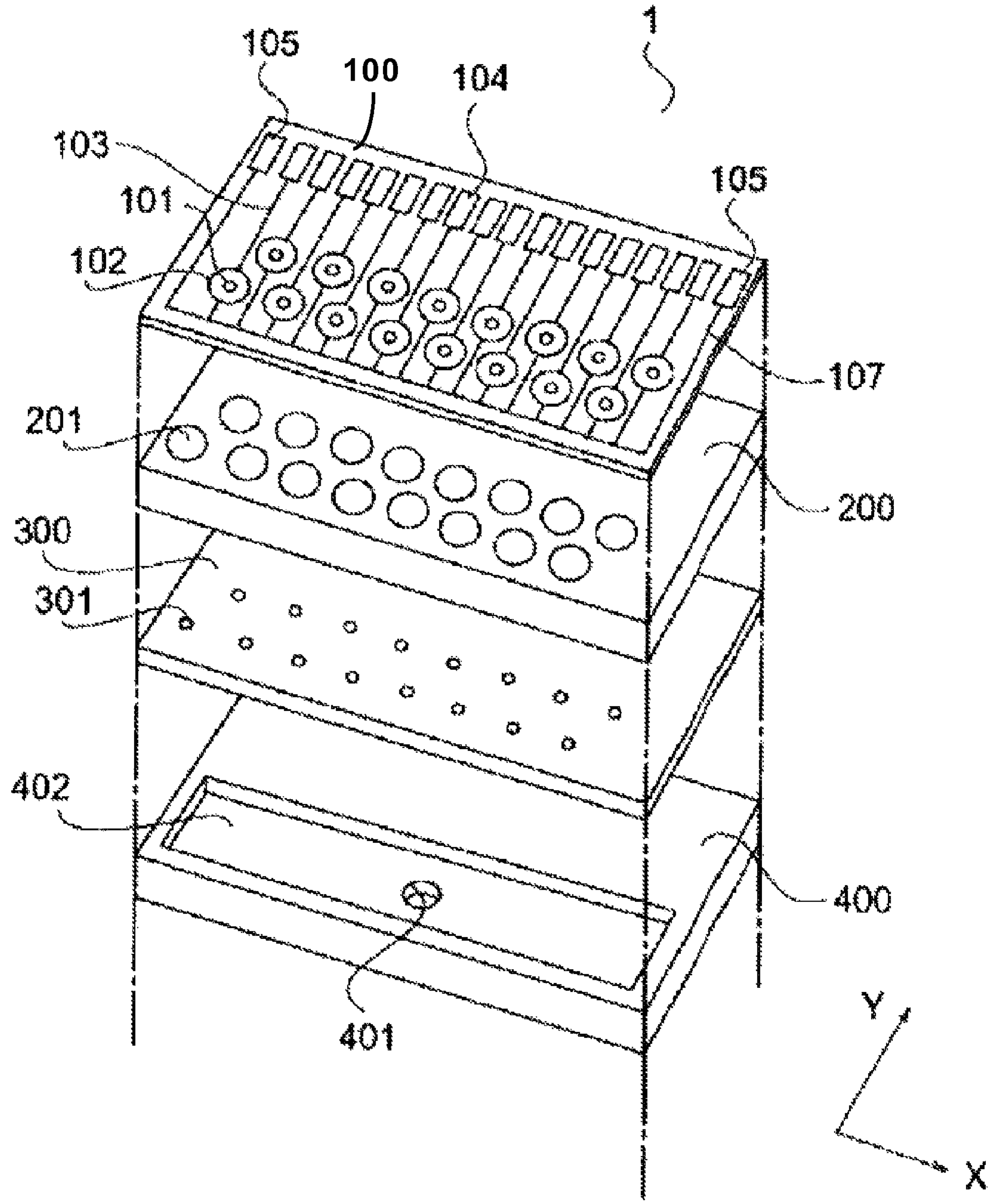

FIG. 2

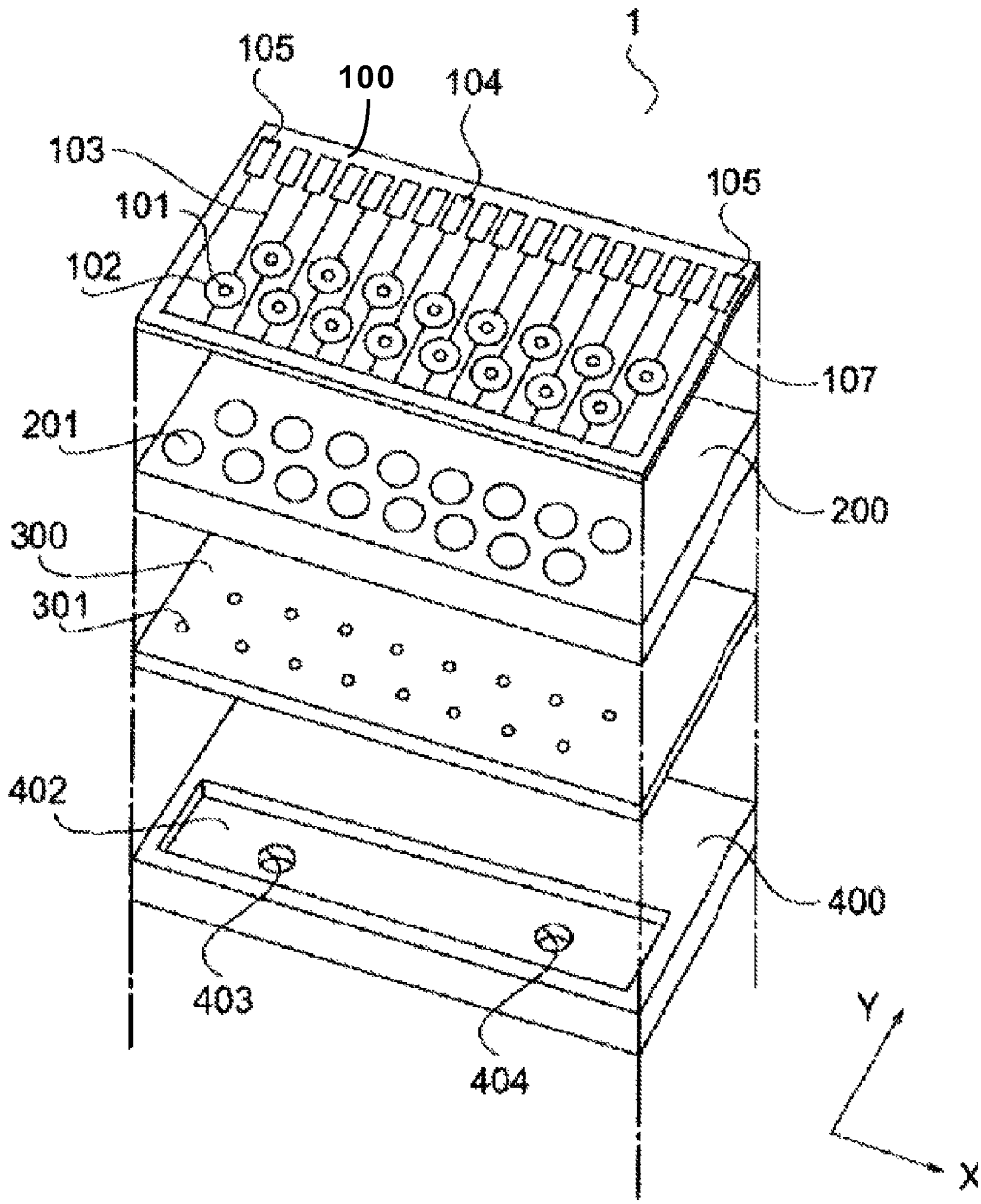
1
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FIG. 3

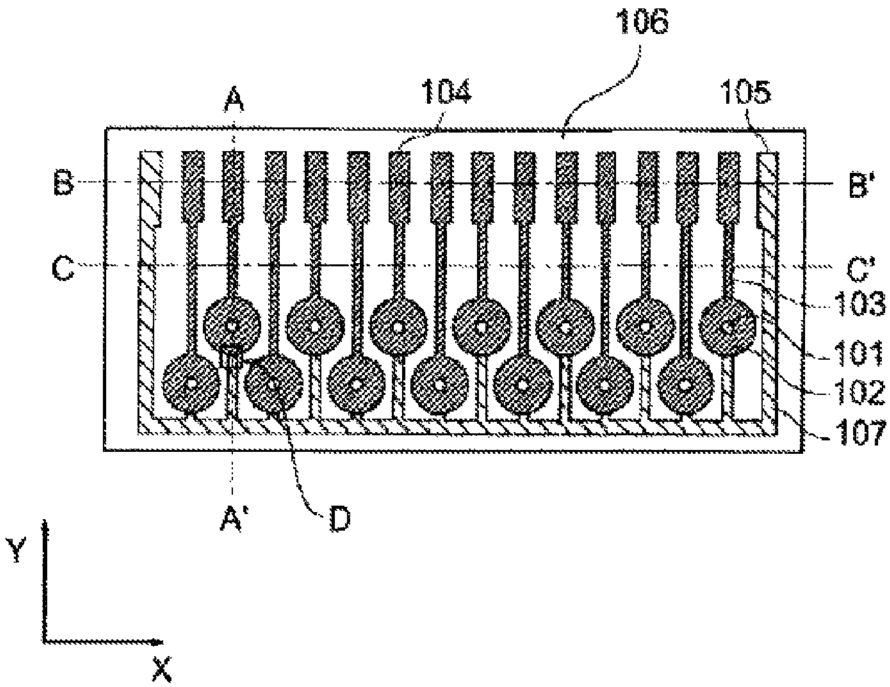


FIG. 4

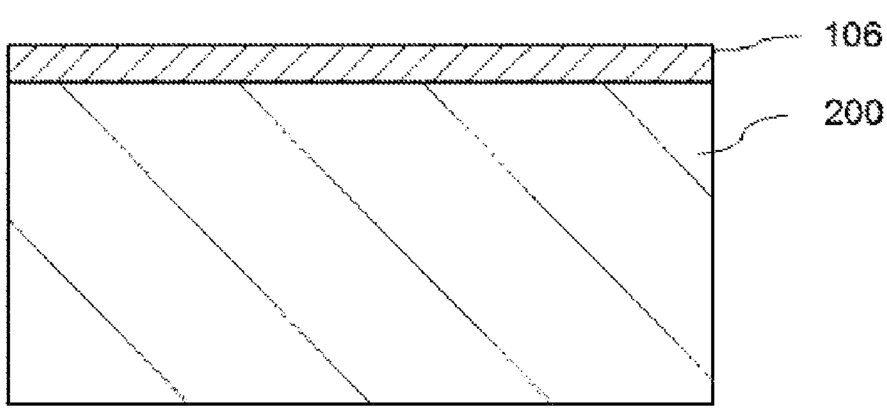

FIG. 5

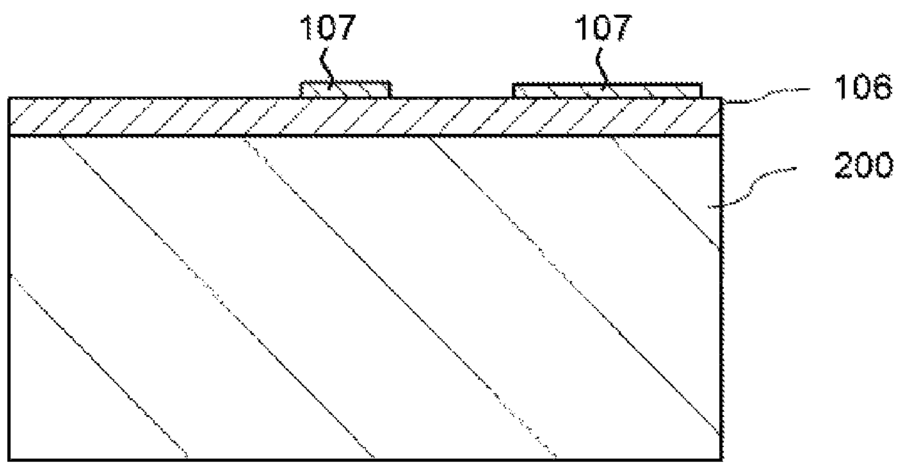


FIG. 6

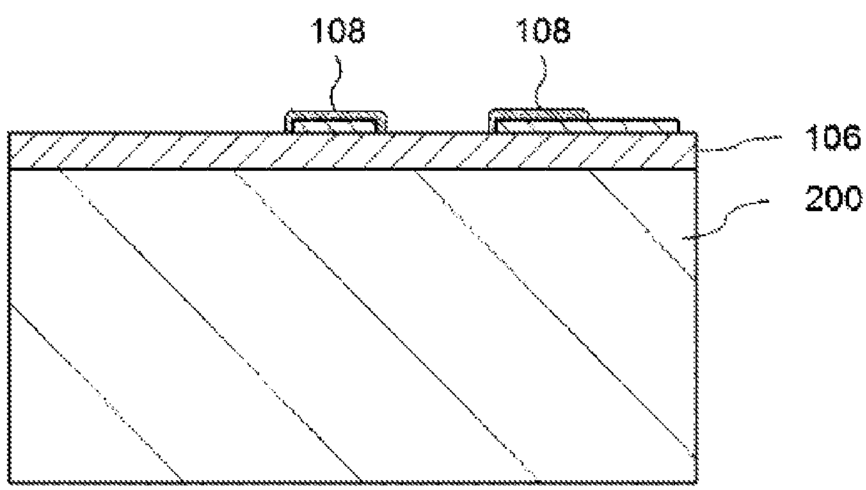

FIG. 7

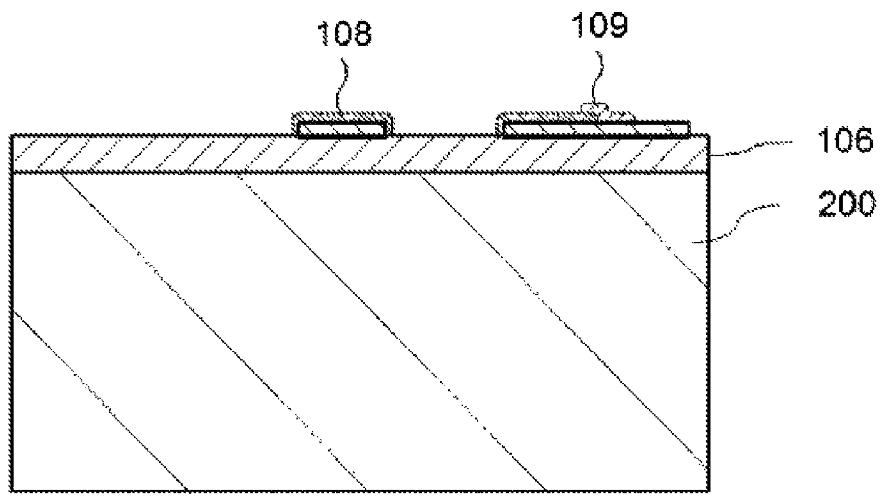


FIG. 8

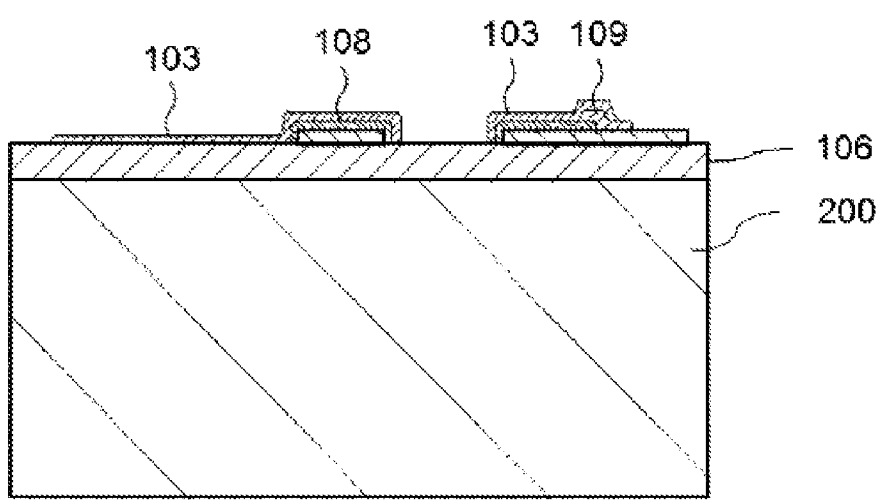

*FIG. 9*

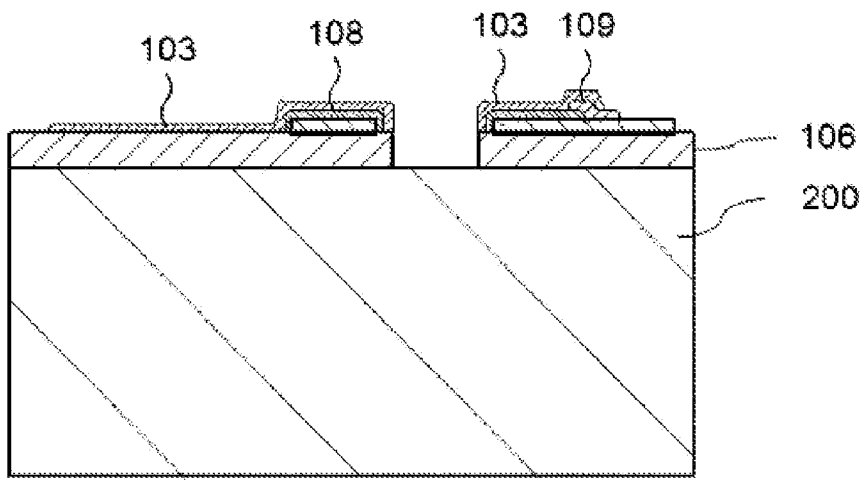


*FIG. 10*

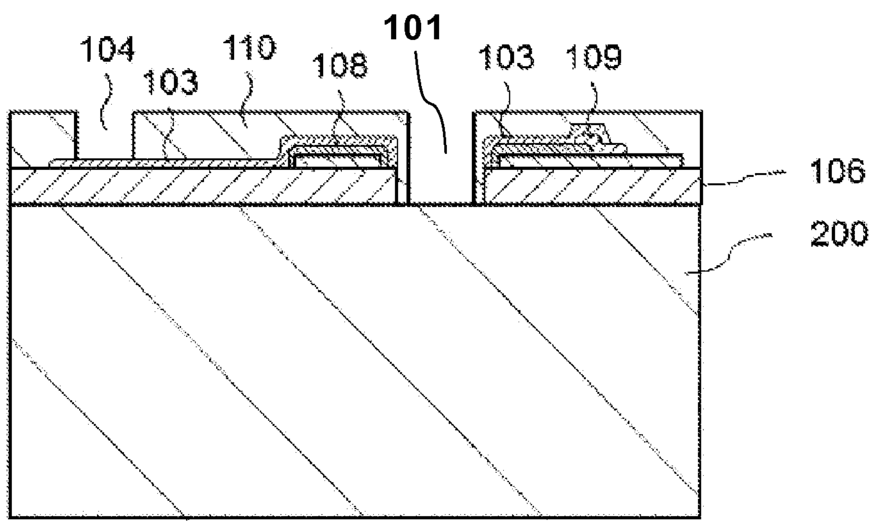

FIG. 11

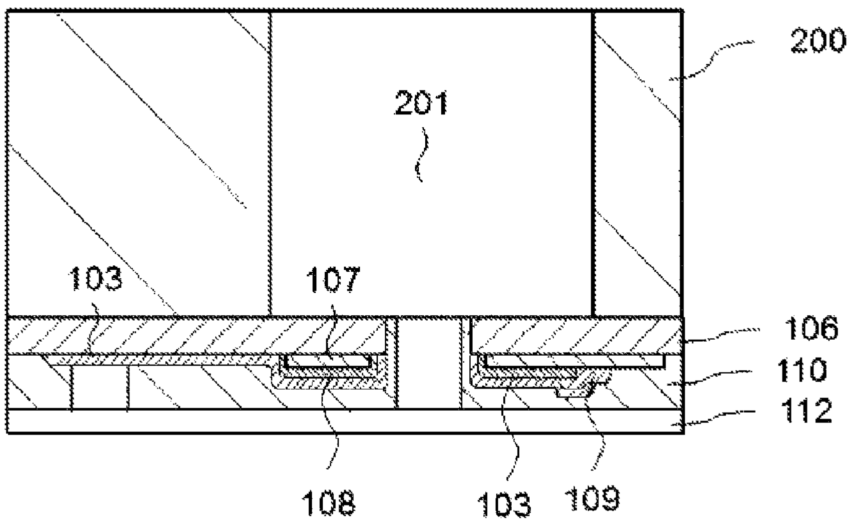
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FIG. 12

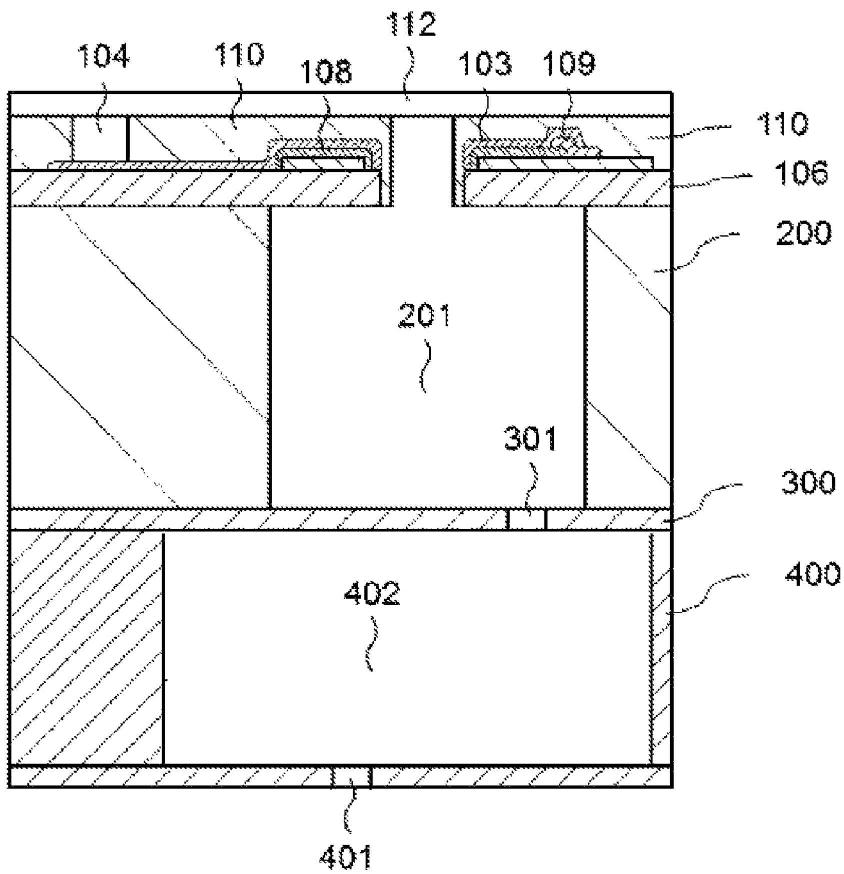
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FIG. 13

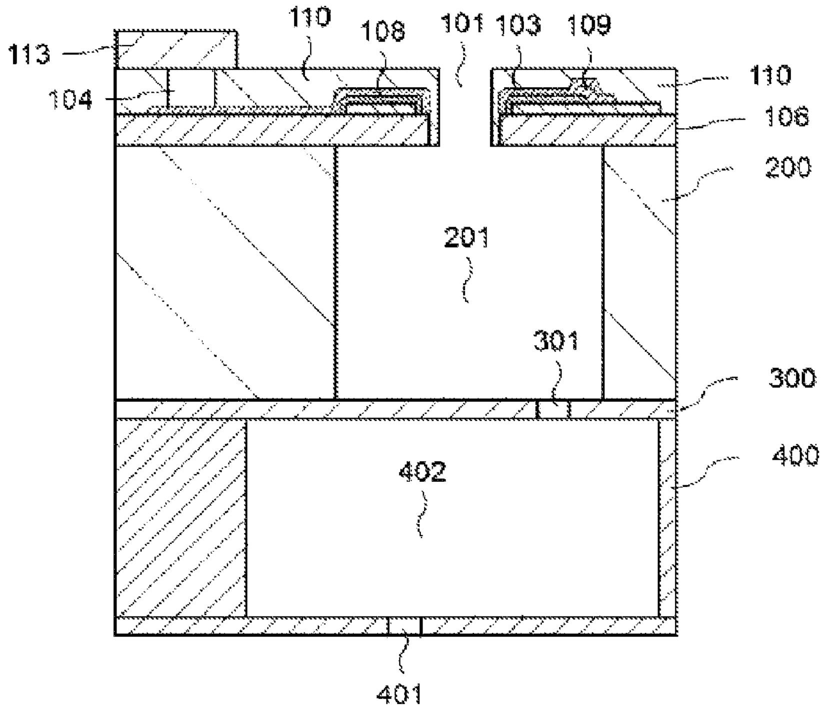
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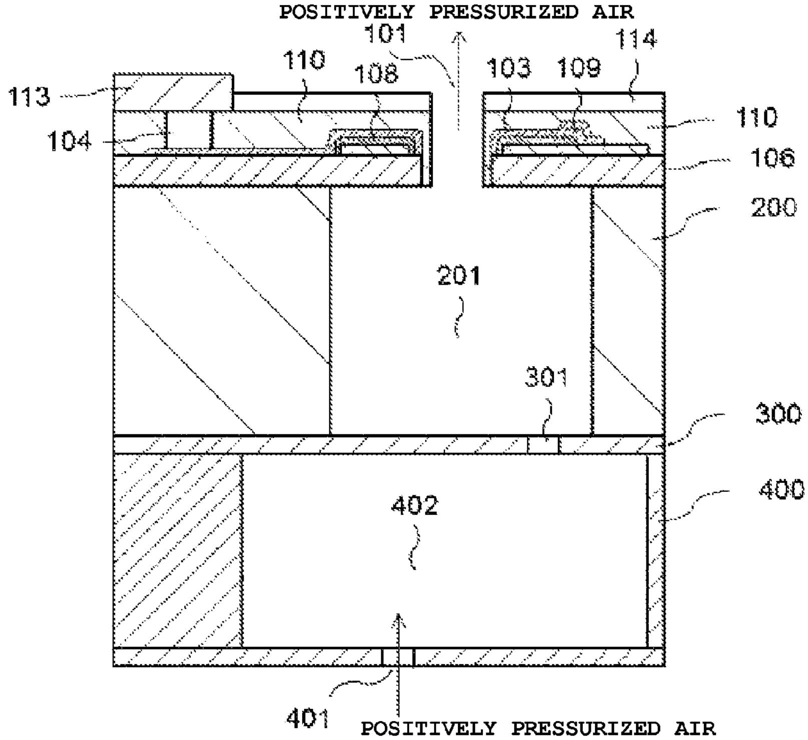
FIG. 14


POSITIVELY PRESSURIZED AIR
101
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401
POSITIVELY PRESSURIZED AIR

FIG. 15

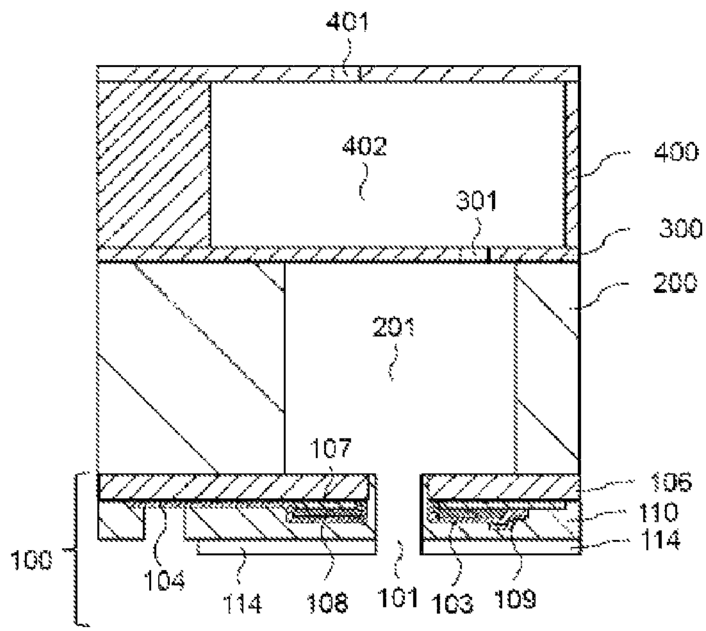
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FIG. 16

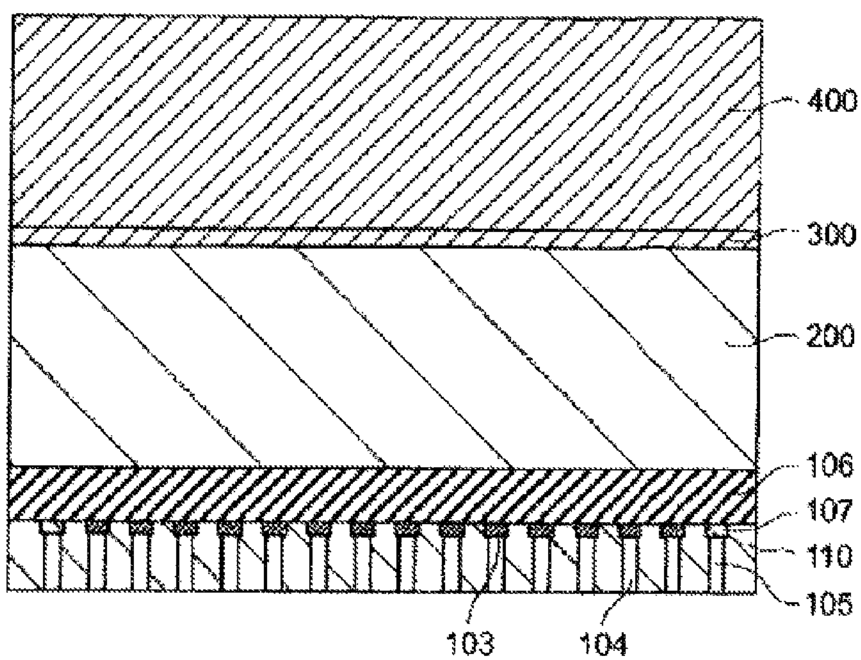
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FIG. 17

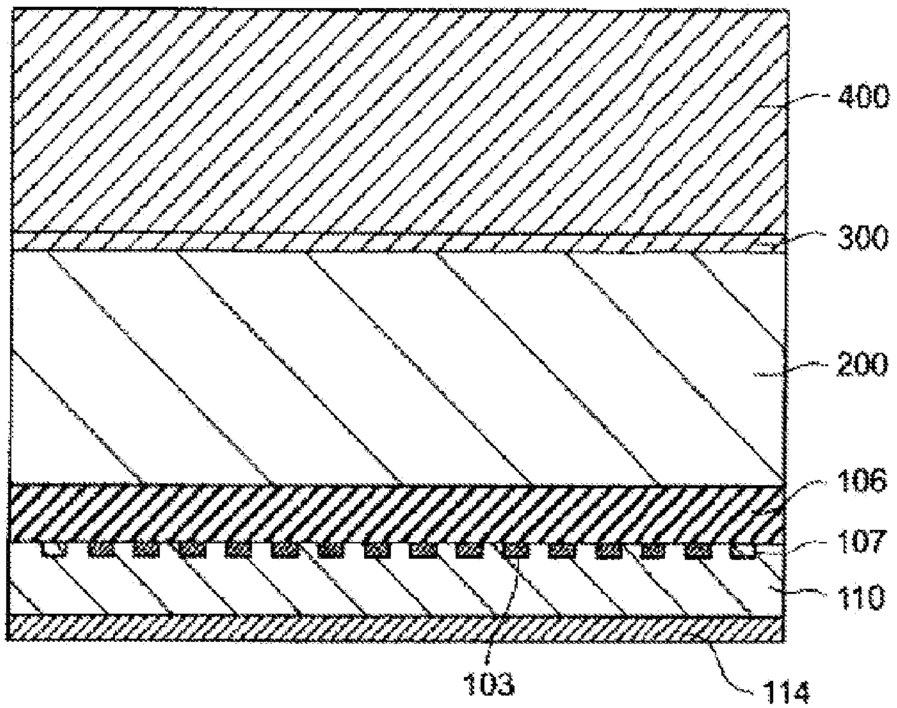


FIG. 18

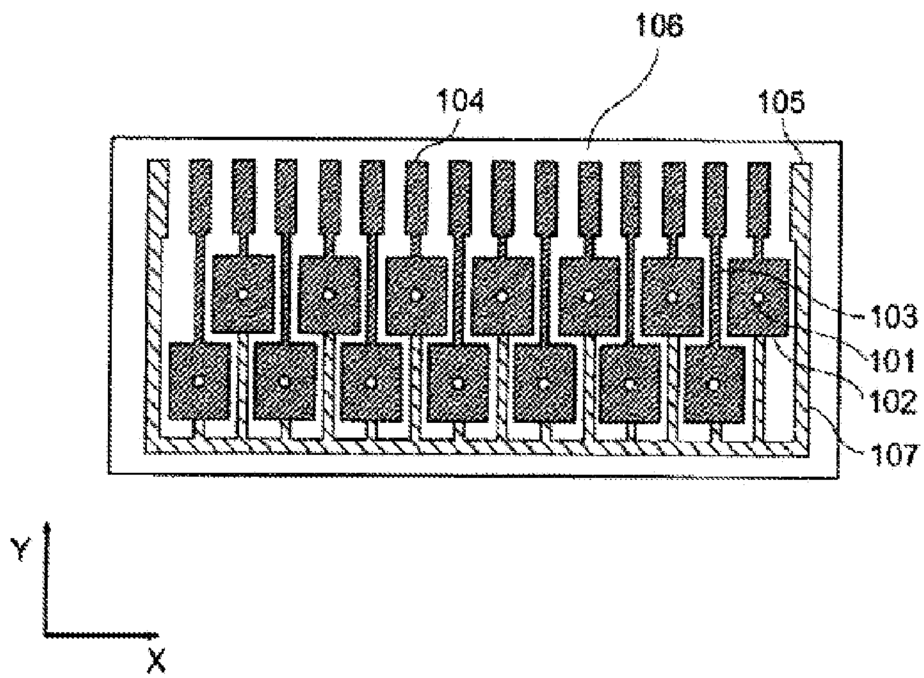

FIG. 19

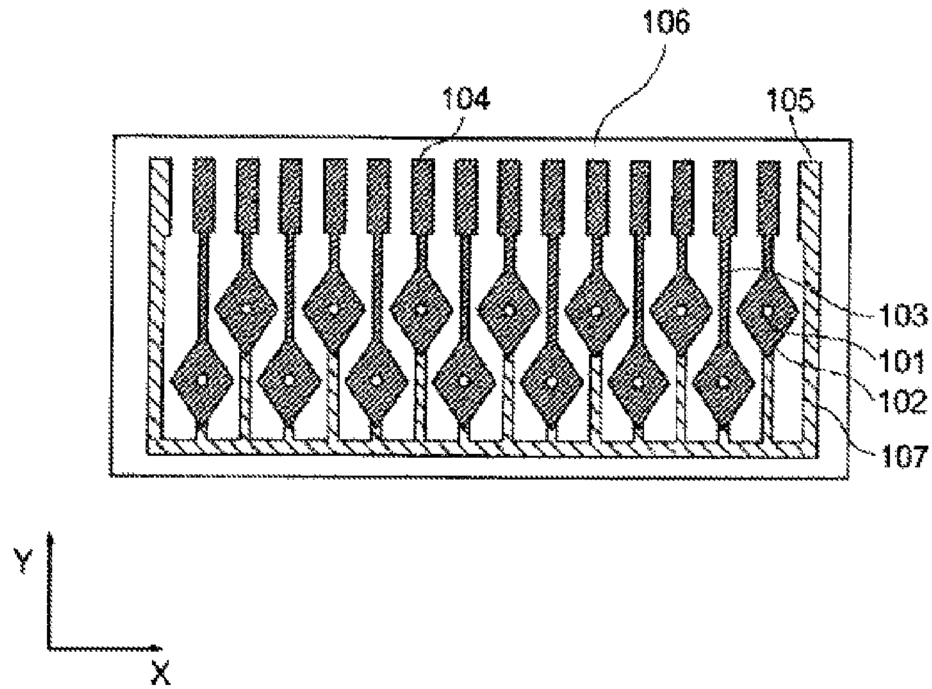

FIG. 20

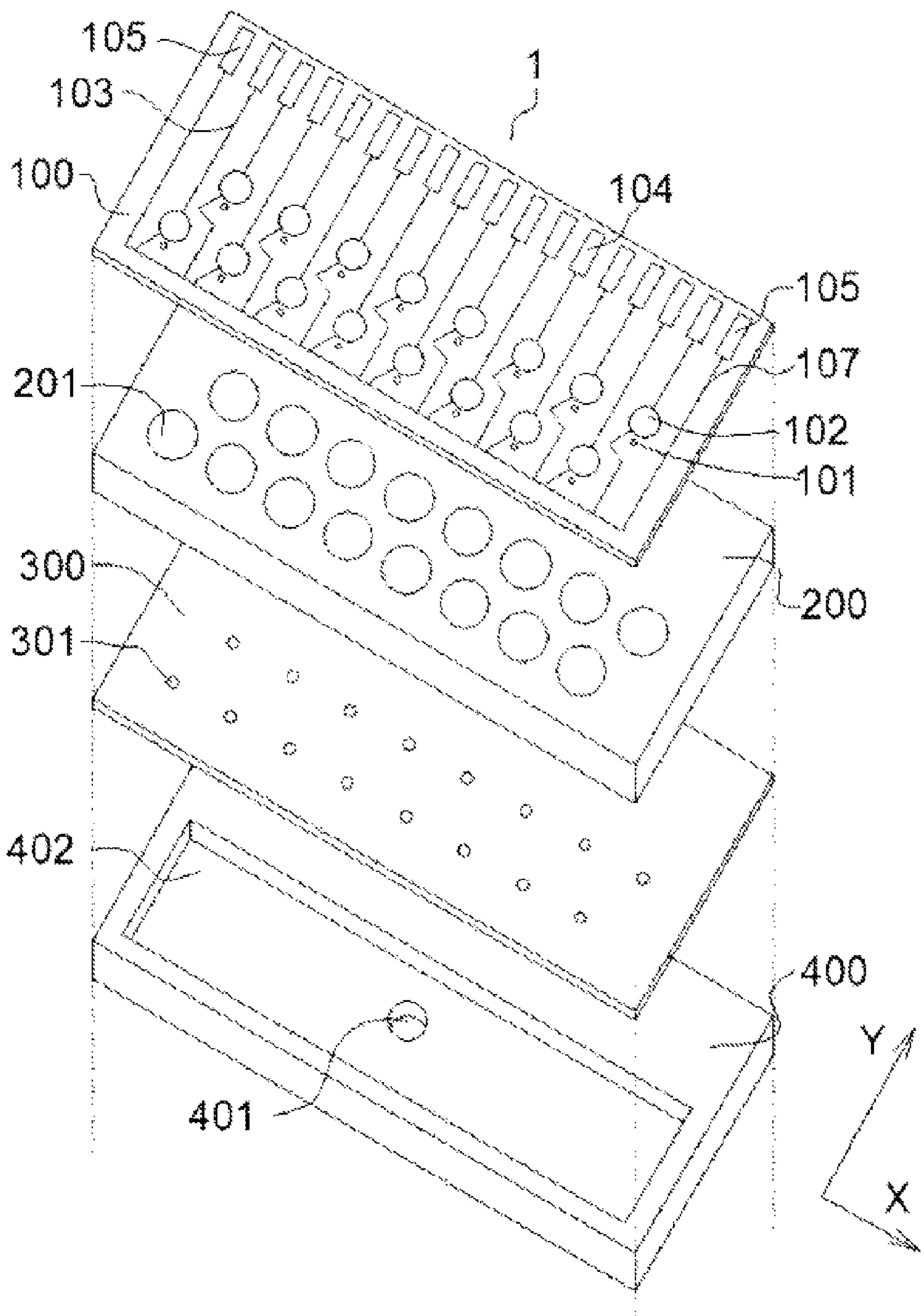

FIG. 21

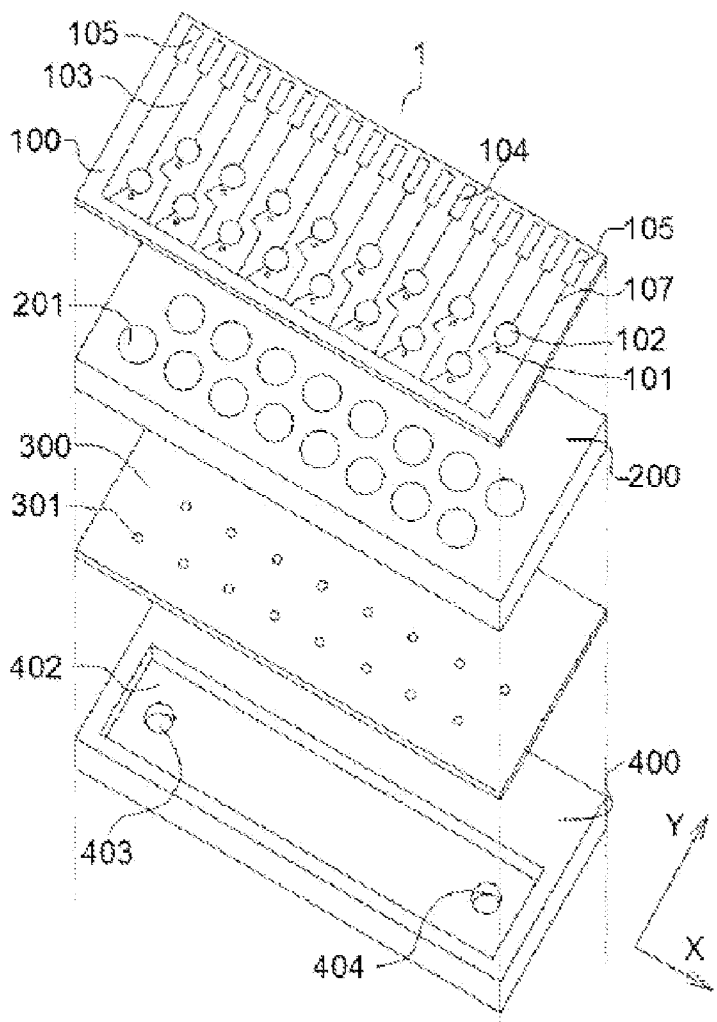
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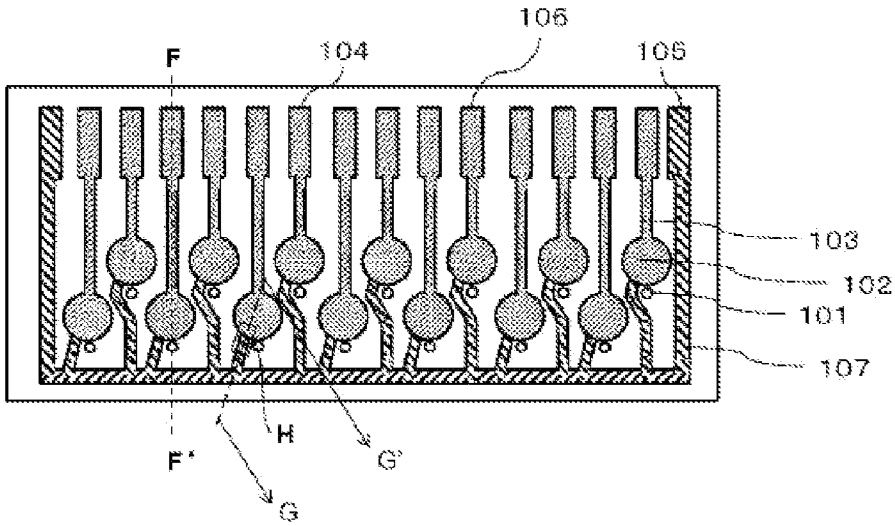
FIG. 22



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G'
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FIG. 23

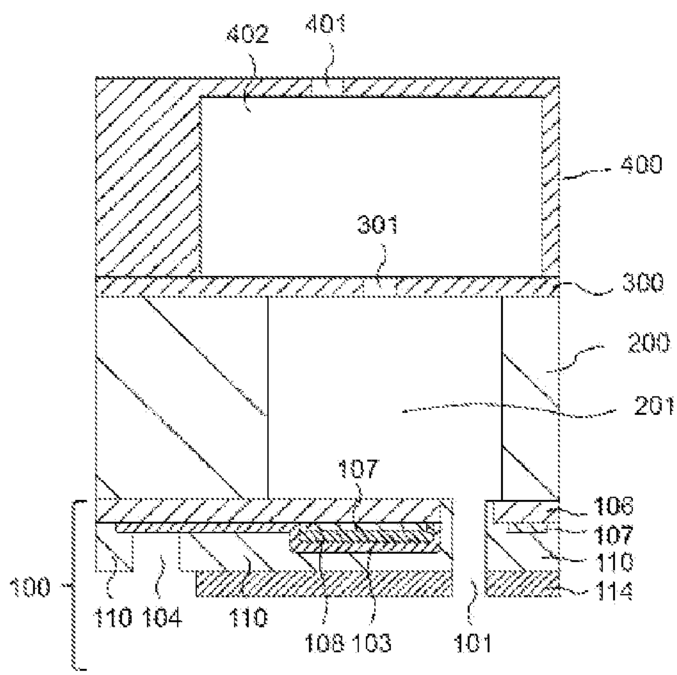

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FIG. 24

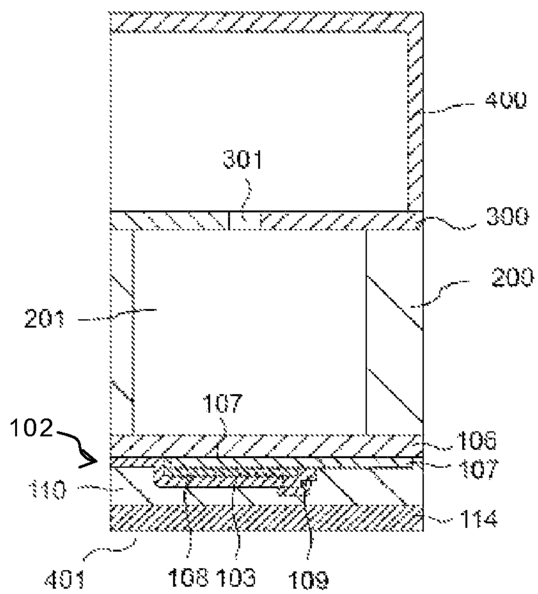

*FIG. 25*

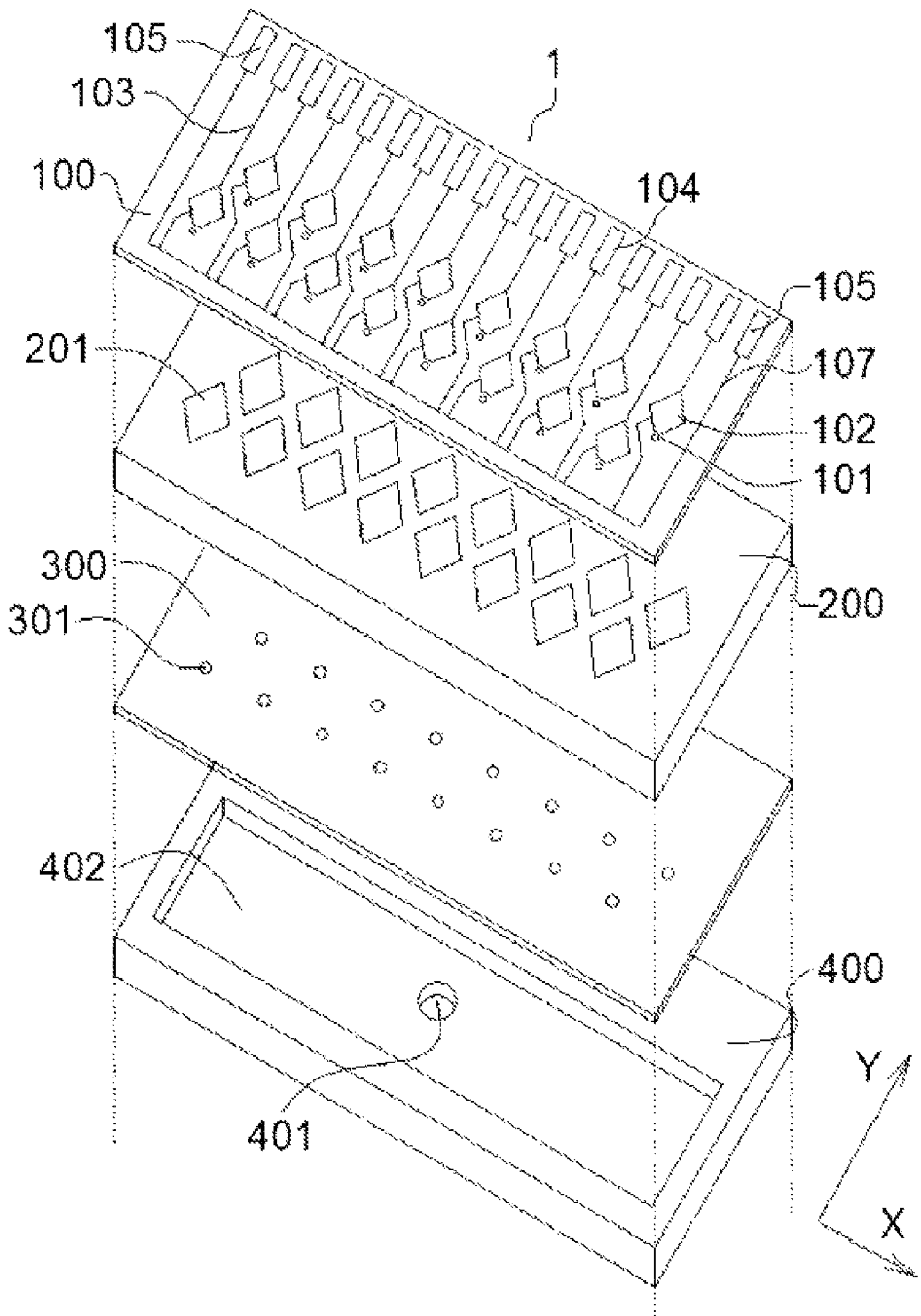

FIG. 26

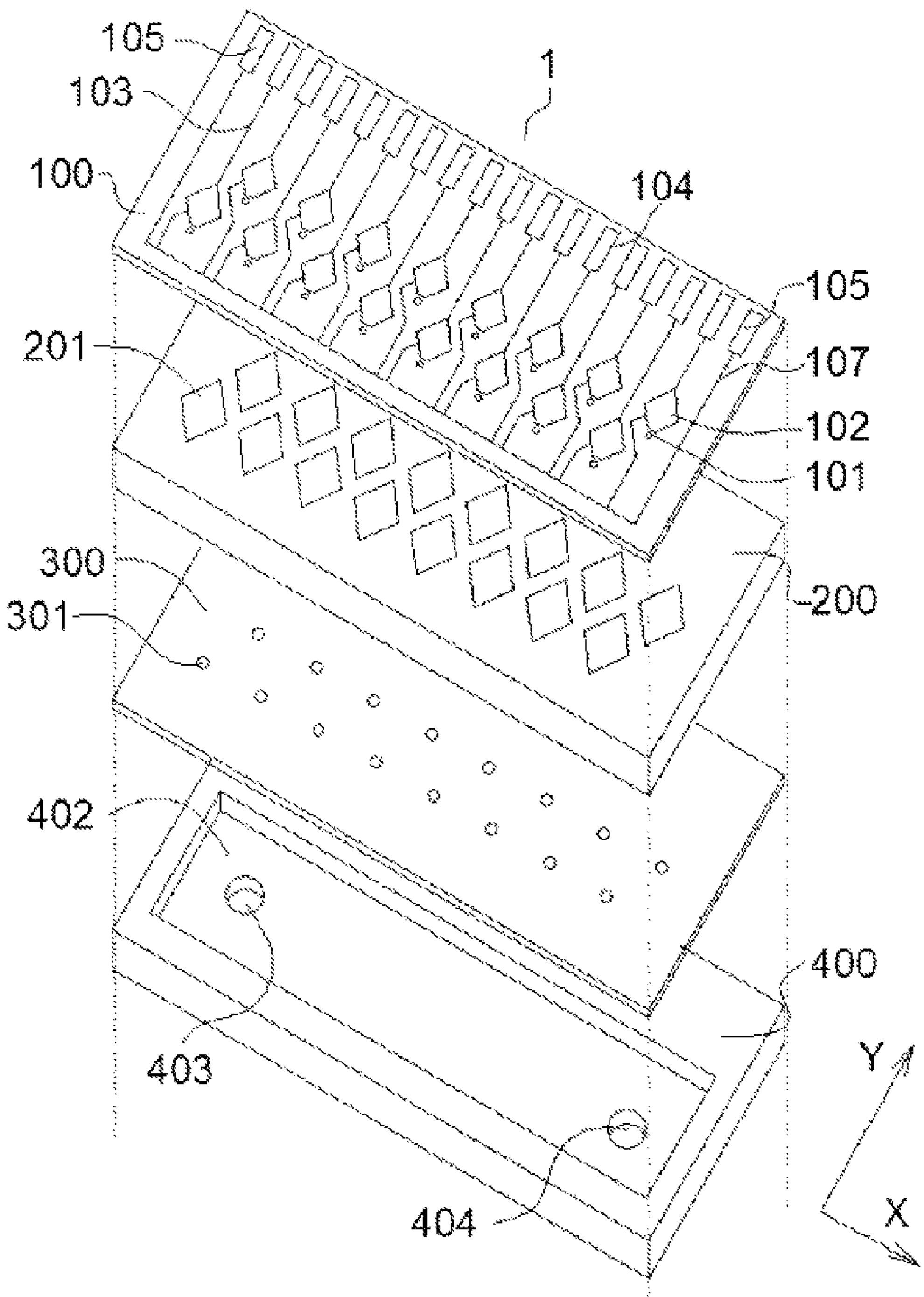
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FIG. 27

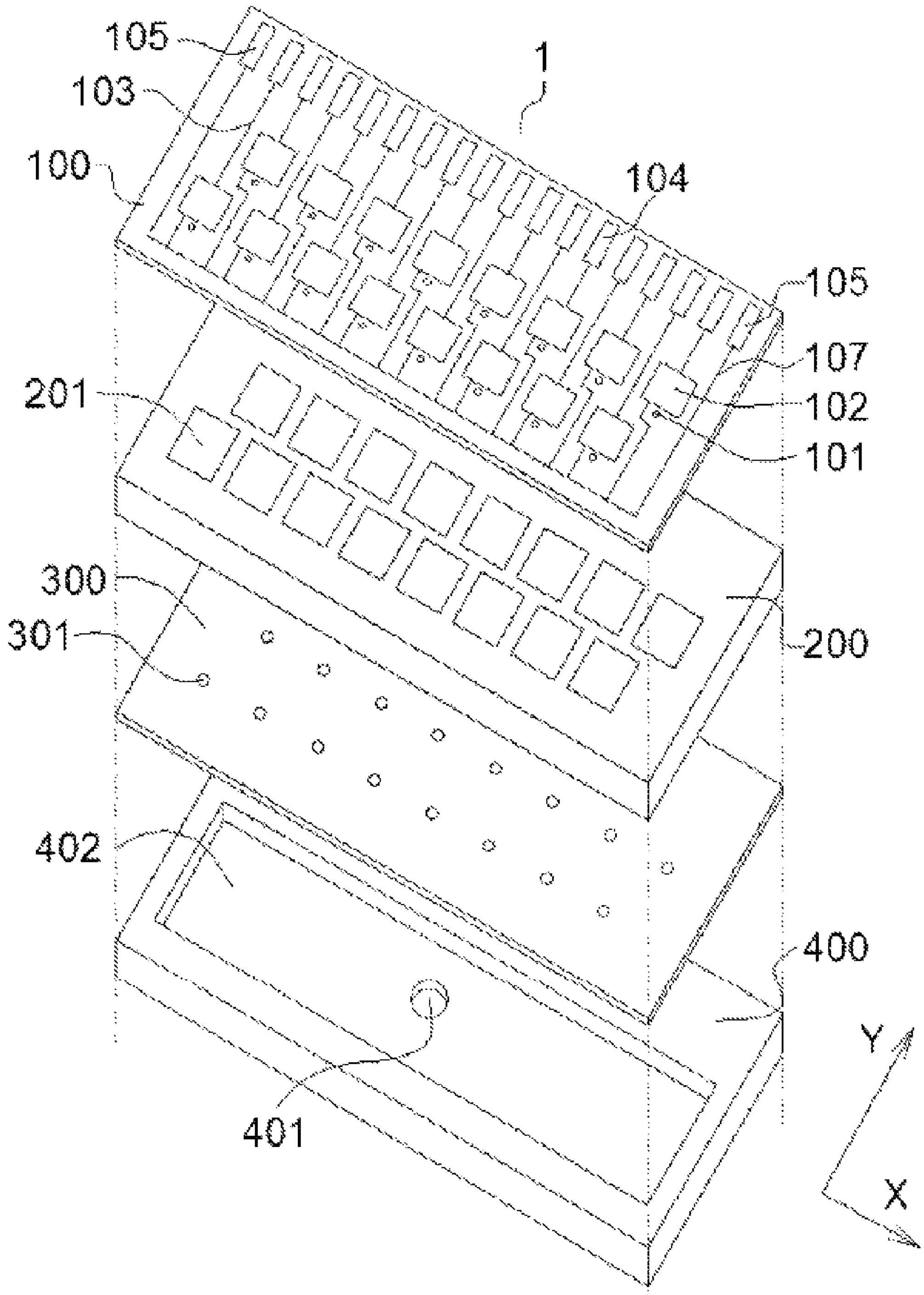
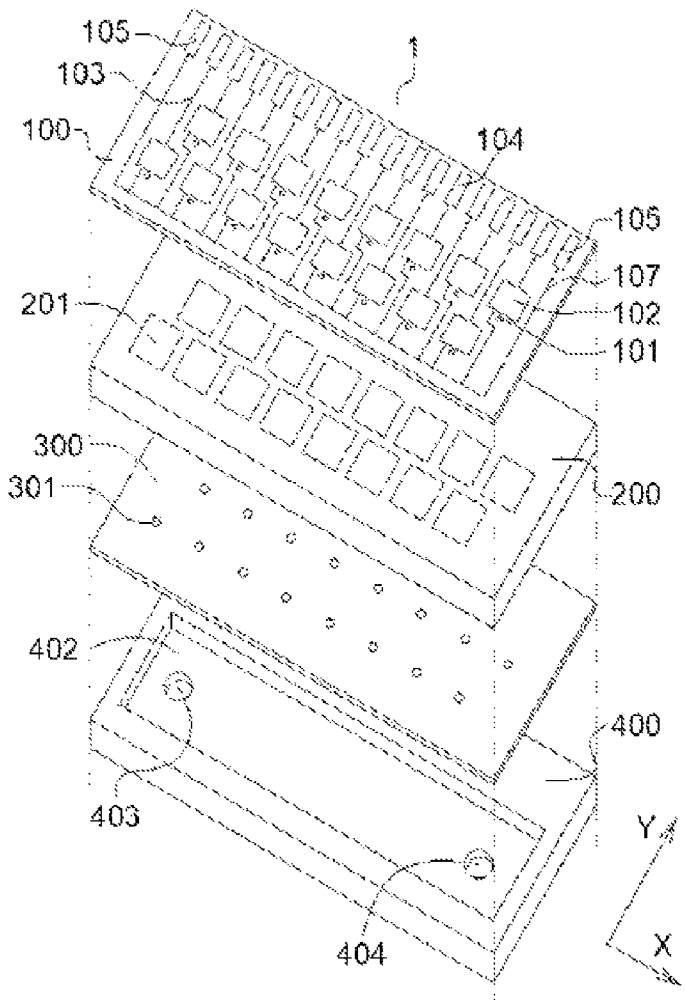


FIG. 28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# INK JET HEAD AND MANUFACTURING METHOD OF THE SAME

## CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2012-093854, filed Apr. 17, 2012, the entire contents of which are incorporated herein by reference.

## FIELD

Embodiments described herein relate to an ink jet head for ejecting ink from nozzles to form an image and an ink jet head manufacturing method.

## BACKGROUND

In the related art, there is the on-demand type of inkjet printing system in which ink droplets are ejected from nozzles in an image pattern based upon an image signal, to form the image on a print media such as a paper sheet. The on-demand type of inkjet recording systems mainly consists of two subtypes: the heating element type and the piezoelectric element-type. For the configuration of the heating element type, as power is fed to a heating element in an ink-flow channel, a gas bubble is generated in the ink, and the gas bubble pushes the desired quantity of ink out from the nozzle. For the piezoelectric element-type, the piezoelectric element is energized to create waves in the ink to eject the desired quantity of the ink stored in the ink chamber out of the nozzle.

A piezoelectric element (piezo-element) is an element that converts a voltage to a force. When an electric field is applied to the piezoelectric element, stretching or shear deformation of the element takes place, causing a change in the volume of the ink chamber against which it is placed. A typical piezoelectric element is made of lead titanate zirconate.

In the configuration of an ink jet head using a piezoelectric element, a nozzle substrate is formed from a piezoelectric material. For this ink jet head, electrodes are formed on the two surfaces of the nozzle substrate to either side of the nozzle. The ink enters an area between the nozzle substrate and a substrate that supports the nozzle substrate. The ink forms a meniscus inside the nozzle and is held inside the nozzle. When a driving waveform is applied to the electrodes of the nozzle substrate to vibrate the piezoelectric element, the piezoelectric element around the nozzle vibrates. As the piezoelectric element vibrates, an ultrasonic wave vibration is generated inside the nozzle so that the ink in the meniscus is ejected. As the piezoelectric element on the nozzle substrate is energized to vibrate, vibration energy is concentrated from a peripheral edge portion of an ink droplet-ejection opening towards a center thereof so that the ink droplets are ejected from an ink surface in a perpendicular direction.

It is difficult to form plural nozzles with high precision and at low cost with respect to the piezoelectric element.

## DESCRIPTION OF THE DRAWINGS

FIG. **1** is an exploded perspective view of an ink jet head in a first embodiment.

FIG. **2** is an exploded perspective view of the ink jet head of the first embodiment as another example different from the view shown in FIG. **1**.

FIG. **3** is a plan view illustrating the ink jet head in the first embodiment.



FIG. **4** is a cross-sectional view illustrating the ink jet head shown in FIG. **3** as seen from the left hand side to the right hand side with respect to the A-A' axis.

FIG. **5** is a diagram illustrating a shared electrode formed as a layer on a vibration plate in an operational step after the step shown in FIG. **4**.

FIG. **6** is a diagram illustrating a piezoelectric layer formed on the shared electrode in an operational step after the step shown in FIG. **5**.

FIG. **7** is a diagram illustrating an insulating layer formed on the shared electrode and the piezoelectric layer in an operational step after the step shown in FIG. **6**.

FIG. **8** is a diagram illustrating a wiring electrode formed on the shared electrode, the piezoelectric layer and the vibration plate in an operational step after the step shown in FIG. **7**.

FIG. **9** is a diagram illustrating a state in which a portion of the vibration plate is pierced through in an operational step after the step shown in FIG. **8**.

FIG. **10** is a diagram illustrating a protective layer formed on the vibration plate, the wiring electrode, the shared electrode, and the insulating layer in an operational step after the step shown in FIG. **9**.

FIG. **11** is a diagram illustrating a state in which an ink pressure chamber structural body is arranged with respect to the flipped ink pressure chamber structural body in an operational step after the step shown in FIG. **10**.

FIG. **12** is a diagram illustrating a state in which a separate plate and an ink-feeding path structural body are boned to the ink pressure chamber structural body in an operational step after the step shown in FIG. **11**.

FIG. **13** is a diagram illustrating a state in which an electrode terminal section cover tape is bonded to a protective layer wiring electrode terminal section in an operational step after the step shown in FIG. **12**.

FIG. **14** is a diagram illustrating a state in which an ink-repulsion layer is formed on the protective layer in an operational step after the step shown in FIG. **13**.

FIG. **15** is a cross-sectional view illustrating the ink jet head completed after the operational steps shown in FIG. **4** to FIG. **14**.

FIG. **16** is a cross-sectional view taken across the B-B' axis of the ink jet head shown in FIG. **3**.

FIG. **17** is a cross-sectional view taken across the C-C' axis of the ink jet head shown in FIG. **3**.

FIG. **18** is a diagram illustrating an ink jet head in a second embodiment.

FIG. **19** is a diagram illustrating an ink jet head in a third embodiment.

FIG. **20** is a diagram illustrating an ink jet head in a fourth embodiment.

FIG. **21** is a diagram illustrating the ink jet head in the fourth embodiment as another example that is different from the diagram shown in FIG. **20**.

FIG. **22** is a plane view of a nozzle plate shown in FIG. **21** as viewed from an ink-ejecting side.

FIG. **23** is a cross-sectional view taken across the F-F' axis of the ink jet head shown in FIG. **22**.

FIG. **24** is a cross-sectional view taken across the G-G' axis of the ink jet head shown in FIG. **22**.

FIG. **25** is a diagram illustrating an ink jet head in a fifth embodiment.

FIG. **26** is a diagram illustrating the ink jet head in the fifth embodiment as another example that is different from the diagram shown in FIG. **25**.

FIG. **27** is a diagram illustrating an ink jet head in a sixth embodiment.

FIG. **28** is a diagram illustrating the ink jet head in the sixth embodiment as another example that is different from the diagram shown in FIG. **27**.

## DETAILED DESCRIPTION

In general, a detailed description according to one embodiment of the present invention will be explained with reference to the figures.

The ink jet head in an embodiment of the present invention has the following components: vibration plates, each having an opening with a first diameter; ink pressure chambers, each communicating with the opening and arranged on one surface of the corresponding vibration plate; first electrodes, each formed on the other surface of the vibration plate; a piezoelectric layer, each portion of which is formed on the first electrode on a region that surrounds the opening, which, when a driving voltage is applied, deforms the vibration plate to expand or contract the ink pressure chamber; second electrodes, each formed on the piezoelectric layer; a protective layer, each portion of which is at least formed on the vibration plate, and the second electrode and has a nozzle for ejecting the ink with a diameter smaller than the first diameter arranged in the opening; and an ink-feeding mechanism that feeds the ink into the ink pressure chambers.

(First Embodiment)

FIG. **1** is an exploded perspective view of an ink jet head in a first embodiment.

As shown in FIG. **1**, an ink jet head **1** includes a nozzle plate **100**, an ink pressure chamber structural body **200**, a separation plate **300**, and an ink-feeding path structural body **400**.

The nozzle plate **100** includes plural nozzles **101** (ink-ejecting holes) for ink injection that extend through the thickness of the nozzle plate **100** in a direction substantially perpendicular to the planar face thereof.

The ink pressure chamber structural body **200** includes a plurality of ink pressure chambers **201** each of which corresponds to one of the plural nozzles **101**. Each of the ink pressure chambers **201** overlies and is in fluid communication with a corresponding nozzle **101**.

On the separation plate **300**, there are provided ink throttles **301** (ink-feeding openings to the ink pressure chambers) which individually connect to one of the ink pressure chambers **201** formed in the ink pressure chamber structural body **200**.

An ink pressure chamber **201** and an ink throttle **301** are each arranged to correspond to one of the plural nozzles **101**. The plural ink pressure chambers **201** are connected via the ink throttles **301** to an ink-feeding path **402**.

The ink pressure chambers **201** hold the ink for forming the image. Due to deformation of the nozzle plate **100**, the pressure of the ink in each of the ink pressure chambers **201** is changed, and the ink is ejected from each of the nozzles **101**. In this case, the separation plate **300** has the function to enclose the ink, or to maintain the pressure generated in the ink pressure chambers **201** to prevent the pressure from escaping to the ink-feeding path **402**. For this purpose, the diameter of the ink throttles **301** is ¼ of the diameter of the ink pressure chambers **201** or smaller.

The ink-feeding path **402** is provided within the ink-feeding path structural body **400**. In the ink-feeding path structural body **400**, there is an ink-feeding port **401** for feeding the ink from outside of the ink jet head. The ink-feeding path **402** is a reservoir or manifold that is positioned and sized to be in fluid communication with all of the plural ink pressure chambers **201** so that the ink can be simultaneously fed to all of the ink pressure chambers **201**.

In the embodiment, the ink pressure chamber structural body **200** is formed from a 725-μm-thick silicon wafer. Each of the ink pressure chambers **201** has a cylindrical shape with diameter of 240 μm. There is the nozzle **101** arranged at the center of the diameter of each of the right cylindrical ink pressure chambers **201**.

The separation plate **300** is a 200-μm-thick stainless steel plate. In the embodiment, the ink throttles **301** each have a diameter of 60 μm. The ink throttles **301** are formed to be substantially identical to suppress differences in the shape of the ink throttles **301** so that the fluid resistance of the ink-flow channels to the ink pressure chambers **201** are almost the same. Incidentally, the ink throttles **301** can be removed if the diameter or depth of the ink pressure chamber body **201** is adequately designed. In such a case, even if the ink separation plate **300** having the ink throttles **301** is not built in the inkjet head **1**, ink drops still can be discharged from the inkjet head **1**.

In the embodiment, the ink-feeding path structural body **400** is a 4-mm-thick stainless steel plate. The ink-feeding path **402** has a depth of 2 mm from the surface of the stainless steel plate. An ink-feeding port **401** is provided at, or nearly at, the center of the ink-feeding path **402**. The ink-feeding port **401** is formed so that the fluid resistance of the ink flow channels to the ink pressure chambers **201** is almost the same.

The configuration shown in FIG. **2** differs from the configuration shown in FIG. **1** in that a circulating ink-feeding port **403** and a circulating ink-exhausting port **404** are arranged near the two ends of the ink-feeding path **402**, so that the ink can be circulated through the ink-feeding path **402**. By circulating the ink, it is possible to keep the ink temperature in the ink-feeding path **402** at a constant value. Consequently, compared to the ink jet head shown in FIG. **1**, this configuration can suppress the temperature rising in the ink jet head caused by the heat generated by the deformation of the nozzle plate **100**.

The nozzle plate **100** has a monolithic structure formed in the layer-formation process to be explained later on the ink pressure chamber structural body **200**.

The ink pressure chamber structural body **200**, the separation plate **300**, and the ink-feeding path structural body **400** are anchored together using an epoxy resin adhesive so that the nozzles **101** and the ink pressure chambers **201** maintain a prescribed positional relationship among themselves.

The ink pressure chamber structural body **200** is formed from a silicon wafer, and the separation plate **300** and ink-feeding path structural body **400** are made of stainless steel. However, the materials of these structural bodies **200**, **300**, and **400** are not limited to silicon wafer and stainless steel. The structural bodies **200**, **300**, and **400** may also be made of other materials as long as there is no influence on the generation of the ink-ejecting pressure in consideration of the difference in the expansion coefficient from the nozzle plate **100**. Examples of the ceramic materials that may be used in this case include alumina ceramics, zirconia, silicon carbide, silicon nitride, barium titanate, and other nitrides and oxides. Examples of the resin materials that may be used in this case include ABS (acrylonitrile butadiene styrene), polyacetal, polyamide, polycarbonate, polyether sulfone, and other plastic materials. Also, metal materials (alloys) may be used. Typical examples include aluminum, titanium, and other materials.

In the following, the configuration of the nozzle plate **100** will be explained with reference to FIG. **3**. FIG. **3** is a plan view of the nozzle plate **100** as viewed from the ink-ejecting side.

The nozzle plate **100** has the nozzles **101** that eject the ink and actuators **102** that generate the pressure for ejecting the ink from the nozzles **101**. The nozzle plate **100** has wiring electrodes **103** and a shared electrode **107** for transmitting a signal for driving the corresponding actuators **102**. Here, the nozzle plate **100** has wiring electrode terminal sections **104**, which are a portion of the wiring electrodes **103** and which receive the signal for driving the inkjet head **1** from outside of the inkjet head **1**, and common or shared electrode terminal sections **105**, which, similarly, are a portion of the shared electrode **107** and receive the signal for driving the ink jet head **1**.

The actuators **102**, the wiring electrodes **103**, the wiring electrode terminal sections **104**, the shared electrode **107**, and the shared electrode terminal sections **105** are formed on a vibration plate **106**.

The nozzles **101** are formed to extend through the nozzle plate **100**. For each of the ink pressure chambers **201**, the center of the circular cross-section thereof is aligned with the center of the corresponding nozzle **101**. The ink is fed from each ink pressure chamber **201** into the corresponding nozzle **101**. Due to the operation of the actuator **102** corresponding to the nozzle **101**, the vibration plate **106** deforms, and, due to the variation in the pressure generated in the ink pressure chamber **201**, the ink fed into the nozzle **101** is ejected. All of the nozzles **101** work in the same way.

In the embodiment, the nozzles **101** have a right cylindrical shape and have a diameter of 20 μm.

The actuators **102** are each formed from a piezoelectric layer. The actuators **102** each work due to the piezoelectric layer and the 2 electrodes (the wiring electrode **103** and the shared electrode **107**) that have the piezoelectric layer inserted between them. When the piezoelectric layer is formed, polarization takes place in the direction perpendicular to the surface of the piezoelectric layer. When an electric field in the same direction as the direction of the polarization is applied via the electrodes on the piezoelectric layer, the actuators **102** stretch or contract in the direction orthogonal to the electric field direction. This stretching/contraction is exploited to cause the vibration plate **106** to deform in the direction perpendicular to the nozzle plate **100** to change the volume of the ink pressure chamber **201** so that a change takes place in the pressure on the ink in the ink pressure chamber **201**. The piezoelectric layer has a circular shape. The piezoelectric layer is formed concentric to the ejection-side opening of the nozzle **101**. In the embodiment the diameter of the circular piezoelectric layer is 170 μm. That is, the piezoelectric layer surrounds the ejection-side opening of the nozzle **101**.

In the following, an operation of a piezoelectric layer **108** that is a part of the actuators **102** will be described. Here, the piezoelectric layer **108** contracts or stretches in the direction orthogonal to the layer thickness (in the in-plane direction). As the piezoelectric layer contracts, the vibration plate **106** coupled with the piezoelectric layer **108** bends in the direction which expands the ink pressure chamber **201**. The bending to expand the ink pressure chamber **201** leads to the generation of a negative pressure on the ink stored in the ink pressure chamber **201**. Due to the generated negative pressure, ink is fed into the chamber **201** from the ink-feeding path structural body **400**. In contrast, as the piezoelectric layer **108** stretches, the vibration plate **106** coupled to the piezoelectric layer **108** is bent in the direction toward the ink pressure chamber. Due to the bending of the vibration plate **106** in the direction toward the ink pressure chamber **201**, a positive pressure is generated on the ink stored in the ink pressure chamber **201**. Due to the generated positive pressure, an ink droplet is ejected from the nozzle **101** arranged on the vibration plate **106**. When the ink pressure chamber **201** expands or contracts, the portion of the vibration plate near the nozzle deforms in the direction to eject the ink due to the displacement of the piezoelectric layer. In other words, the actuator that ejects the ink functions by bending.

In the embodiment, the actuator **102** having the nozzle **101** arranged at its center is made of a piezoelectric layer with a diameter of 170 μm. To arrange the nozzles **101** at a high density, the actuators **102** are arranged in a zigzag configuration (shifted from each other in lines). As shown in FIG. **3**, plural nozzles **101** are arranged in a linear configuration in the X-axis direction. In the Y-axis direction, there are 2 linear-shaped nozzle columns. In the embodiment, the distance between the centers of the nozzles **101** adjacent to each other in the X-axis direction is 340 μm, and in the direction of the Y-axis, the interval between the **2** columns of the nozzles **101** is 240 μm. With such a configuration, the wiring electrodes **103** pass between the 2 actuators **102** in the X-axis direction.

As the material of the piezoelectric layer, PZT (lead zirconate titanate) is used. Other materials that may also be used there include PTO ($PbTiO_3$: lead titanate), PMNT (Pb ($Mg_{1/3}$ $Nb_{2/3}$) $O_3$—$PbTiO_3$), PZNT (Pb ($Zn_{1/3}Nb_{2/3}$) $O_3$—$PbTiO_3$), ZnO, AIN, etc.

The piezoelectric layer is formed using the RF magnetron sputtering method at a substrate temperature of 350° C. In the embodiment, the layer thickness is 1 μm. After formation of the piezoelectric layer, to imbue the piezoelectric property into the piezoelectric layer, the layer is subjected to heat treatment at 500° C. for 3 hours. As a result, it is possible to achieve excellent piezoelectric performance. Other methods for manufacturing the piezoelectric layer include the CVD (chemical vapor deposition) method, sol-gel method, AD (aerosol deposition) method, hydrothermal synthesis method, etc. The thickness of the piezoelectric layer is determined in consideration of the piezoelectric characteristics, the insulation breakdown voltage, etc. The thickness of the piezoelectric layer is generally in the range from 0.1 μm to 5 μm.

The plural wiring electrodes **103** are one of the two electrodes connected to the piezoelectric layer of each ones of the actuators **102**. The plural wiring electrodes **103** are each arranged on the ejecting side of the nozzle plate **100** with respect to the piezoelectric layer. Each of the wiring electrodes **103** is individually connected to the piezoelectric layer of the corresponding actuator **102**. Each of the wiring electrodes **103** works as an individual electrode to independently operate the piezoelectric layer of a specific nozzle. Each of the wiring electrodes **103** includes an electrode section in a circular shape having a size larger than that of the circular piezoelectric layer, wiring section and a wiring electrode terminal section **104**. At the center of each circular electrode section, the nozzle **101** is formed and extends through the ink ejecting structural body and thus no wiring electrode is formed there.

The plural wiring electrodes **103** are made of a Pt (platinum) thin layer. In the embodiment the thin layer is formed by a sputtering method, and the layer thickness is 0.5 μm. Otherelectrode materials for forming the wiring electrodes **103** include Ni (nickel), Cu (copper), Al (aluminum), Ti (titanium), W (tantalum), Mo (molybdenum), Au (gold), etc. Also, other layer-forming methods may be used, such as a vapor deposition method and a gold plating method. The preferable layer thickness of the wiring electrodes **103** is in the range from 0.01 μm to 1 μm.

The shared or common electrode **107** is the other one of the two electrodes connected to the piezoelectric layer, and is formed on the ink pressure chamber **201** side with respect to the piezoelectric layer. The shared or common electrode **107** is connected to the respective piezoelectric layer portions and shared by them, and works as a common electrode. The shared or common electrode **107** includes circular electrode portions with a diameter smaller than that of the circular piezoelectric layer, wiring sections extending from the circular electrodes in the direction opposite to the individual electrode wiring sections from the actuators **102** and joined together at one side (along the Y axis direction) of the nozzle plate **100** in a common bus, and shared electrode terminal sections **105** extending at either end of the common bus in the y direction to the other side (in the Y direction) of the nozzle plate **100**. At the center of the circular electrode portion, the nozzle **101** is formed. For this purpose, just as for the wiring electrode layer, the shared electrode layer extends concentrically around the nozzle **101**.

The shared electrode **107** is made of a Pt (platinum)/Ti (titanium) thin layer. In the embodiment, the thin layer is formed using the sputtering method, and the layer thickness is 0.5 μm. Other materials that also can be used to form the shared electrode **107** include Ni, Cu, Al, Ti, W, Mo, Au, etc. Other layer-forming methods, such as vapor deposition and gold plating, may also be used. The preferable layer thickness of the shared electrode **107** is in the range from 0.01 μm to 1 μm.

The wiring electrode terminal sections **104** and the shared electrode terminal sections **105** are arranged to receive a signal for driving the actuators **102** from the external driving circuit. The wiring electrodes **103** and the shared electrode **107** are wired to the actuators **102**, and the wiring width in this application example is about 80 μm.

The shared electrode terminal sections **105** are on the two ands (in the X direction) of each wiring electrode terminal section **104**. Because the interval between the wiring electrode terminal sections **104** is 170 μm, the wiring width of the wiring electrode terminal section **104** in the X-axis direction can be made wider than the wiring width of the wiring electrode **103**. Consequently, connection to the external driving circuit becomes easier. The wiring electrodes **103** work as individual electrodes for driving the actuators **102**.

In the following, with reference to the cross-section taken across the A-A' axis in FIG. **3**, the manufacturing method of the ink jet head will be explained.

FIGS. **4** to **15** illustrate a state of operational steps in a processing operation of the ink jet head. The thin layers for forming the ink jet head may also be formed by spin coating.

FIGS. **4** to **10** illustrate the individual layers of electrodes **103**, **107** and piezoelectric **108** used to form the actuators, the actuator **102** final structure shown having the nozzle formed therethrough in FIG. **10**. Generally, the actuator **102** is formed by depositing and patterning, on an underlying dielectric layer **106** formed on structural body **200**, the common electrode **107** material, the piezoelectric material **108** and the second electrode material **103** thereover, covering the patterned materials with a polyimide film, and then pattern etching the polyimide film to provide the nozzle through the center of the stack.

FIG. **4** is a diagram illustrating the configuration in which the layer of the vibration plate **106** is formed on the ink pressure chamber structural body **200**. To form the nozzle plate **100**, a silicon wafer polished to mirror surface quality is used as the ink pressure chamber structural body **200**. In the process of forming the nozzle plate **100**, heating and thin layer formation are carried out repeatedly. Consequently, a silicon wafer with a high heat resistance is used. The silicon wafer is processed to be smoothed to a thickness between 525 μm and 775 μm according to the SEMI (Semiconductor Equipment and Materials International). Instead of the silicon wafer, one may also use heat resistant ceramics, quartz, and various types of metal substrates.

As the vibration plate **106**, an $SiO_2$ (silicon oxide) layer formed using the CVD method is used. In the embodiment, a layer with a thickness of 2 μm is formed over the entire surface of the ink pressure chamber structural body **200**. In lieu of the CVD method, a thermal oxidation method in which heating a silicon wafer in oxygen environment makes a surface of the wafer change to a SiO2 film can be usable in order to form the vibration plate **106**.

The layer thickness of the vibration plate **106** is preferably in the range from 1 to 50 μm. Instead of $SiO_2$, one may also use SiN (silicon nitride), $Al_2O_3$ (aluminum oxide), $HfO_2$ (hafnium oxide), or DLC (diamond-like carbon). The material of the vibration plate **106** is also selected in consideration of a heat resistance, an insulating property (in consideration of the influence of ink denaturing due to driving the actuators **102** when an ink with a high electroconductivity is used), a thermal expansion coefficient, a smoothness, and a wettability with respect to the ink.

FIG. **5** is a diagram illustrating the formation of the shared electrode **107** on the vibration plate **106**. Here, the electrode material is Pt/Ti. The Ti and Pt are sequentially formed using the sputtering method. The layer thickness of the Ti is 0.45 μm, and the layer thickness of the Pt is 0.05 μm.

After formation of the electrode layer, the electrode layer is patterned to form the shared electrode **107** in a shape corresponding to the actuators **102**, the wiring section, and the shared electrode terminal sections **105**. Here, the patterning operation is carried out by forming an etching mask on the electrode layer and then removing the electrode material by etching, except for the portion covered by the etching mask. The etching mask is formed by coating a photosensitive resist onto the electrode layer followed by pre-baking, and then a mask formed in the desired pattern is used for the sequential exposure, development, and treatment operational step, followed by post-baking.

The portion of the shared electrode **107** corresponding to the piezoelectric layer **108** has a circular pattern with an outer diameter, in the embodiment, of 166 μm, which is smaller than the outer diameter of the piezoelectric layer. Since the nozzle **101** is formed at the center of the circular shared electrode **107**, a circular portion free of the electrode film having a diameter of 34 μm is formed concentric to the center of the circular shared electrode **107**. As a result, the vibration plate **106** is exposed in the portion thereof outside of the circular-shaped section of the shared electrode **107** and the wiring section.

FIG. **6** is a diagram illustrating the piezoelectric layer **108** formed on the shared electrode **107**. The piezoelectric layer **108** is formed on the shared electrode **107** and the vibration plate **106**. The piezoelectric layer **108** is made of PZT. The piezoelectric layer **108** with a thickness, in the embodiment, of 1 μm is formed using the sputtering method at a substrate temperature of 350° C. To imbue the PZT thin layer with piezoelectric properties, heat treatment is carried out at 500° C. for 3 hours. As the PZT thin layer is formed, polarization takes place along the layer in the orthogonal direction from the shared electrode **107**.

Patterning of the piezoelectric layer **108** is carried out by etching. After a photosensitive resist is coated onto the piezoelectric layer **108**, pre-baking is carried out. A mask is formed in a desired pattern patterning by exposure, development and fixing, followed by post-baking to form an etching mask of the photosensitive resist. The etching mask is used in the etching operation to form the piezoelectric layer **108** in a desired pattern.

The pattern of the piezoelectric layer **108** has a circular shape with an outer diameter, in the embodiment, of 170 μm. In the circular pattern, in order to form the nozzle **101** at the center of the circular pattern, an inner circular portion, free of the piezoelectric layer, and having a diameter of 30 μm, is formed concentric to the center of the piezoelectric layer **108**. The vibration plate **106** is exposed inwardly of the 30 μm-diameter portion of the piezoelectric layer. Because the diameter of the circular portion free of the piezoelectric layer is 30 μm and the diameter of the circular portion free of the shared electrode **107** is 34 μm, the piezoelectric layer **108** is formed to cover the shared electrode **107** that forms each of the actuators **102**. Because the piezoelectric layer **108** covers the shared electrode **107**, it is possible to guarantee insulation between the shared electrode **107** and the other wiring electrode **103** for applying a voltage to the piezoelectric layer **108**. That is, the piezoelectric layer **108** also insulates the shared electrode **107** from the wiring electrode **103** which functions as the individual electrode for driving the actuator **102**.

FIG. **7** shows an insulating layer **109** formed on portions of the piezoelectric layer **108** and portions of the shared electrode **107** at the site corresponding to D in FIG. **3**. The insulating layer **109** is formed on the piezoelectric layer **108** and the shared electrode **107** to guarantee insulation of the wiring section of the shared electrode **107** and the wiring electrodes **103** that form the actuators **102**. In the embodiment, the thickness of the insulating layer is 0.2 μm, and the material thereof is $SiO_2$. The layer is formed using the CVD method, which can produce excellent insulating properties by forming the layer at a low temperature. The insulating layer **109** is formed only on the surface of the piezoelectric layer **108** and the shared electrode **107**. For this purpose, patterning is carried out. After coating with the resist, pre-baking is carried out. A mask with a desired pattern is used for an exposure, development and fixing are performed, then followed by post-baking to form the etching mask. The obtained etching mask is used to carry out etching to obtain a desired insulating thin layer. In consideration of the processing unevenness precision of the patterning, the insulating layer **109** is patterned to cover a portion of the piezoelectric layer **108**. The quantity of the insulating layer **109** covering the piezoelectric layer **108** is to be limited in such an extent that there is no impediment to the deformation of the piezoelectric layer **108**.

FIG. **8** is a diagram illustrating the wiring electrodes **103** formed as a layer on the vibration plate **106**, the piezoelectric layer **108** and the insulating layer **109**. In the embodiment, the layer thickness of the wiring electrode **103** is 0.5 μm of Pt. The wiring electrodes **103** are formed using the sputtering method. After formation of the electrode layer, the electrode layer is patterned to form the wiring electrodes **103** in a shape corresponding to the actuators **102**, the wiring sections, and the wiring electrode terminal sections **104**. The patterning is carried out by forming an etching mask on the electrode layer, and the electrode material, except for the portions covered by the etching mask, is etched off. The etching mask is formed by coating a photosensitive resist onto the electrode layer, followed by pre-baking, and then a mask formed in a desired pattern is used for an exposure, development and treatment are performed, followed by post-baking.

The portion of the wiring electrode **103** corresponding to the piezoelectric layer **108** has a circular pattern with an outer diameter of 174 μm. At the center of the circular wiring electrodes **103**, the nozzle **101** is formed. For this purpose, a 26-μm-diameter circular portion free of the electrode layer is formed concentric to the center of the circular wiring electrodes **103**. That is, the wiring electrode **103** that forms the actuator **102** is shaped to cover the piezoelectric layer **108**.

Other materials that can be used in forming the wiring electrode layer **103** include Cu, Al, Ag, Ti, W, Mo, Pt and Au. Also, other layer-forming methods may be used for forming the wiring electrode layer **103**, such as the vapor deposition method and gold plating method. The preferable layer thickness of the insulating layer **109** is in the range from 0.01 μm to 1 μm.

FIG. **9** is a diagram illustrating the shape of a circular portion removed from the vibration plate **106** at the center of the circular piezoelectric layer **108**, which is the embodiment has a diameter of 26 μm and is formed concentric to the center of each of the actuators **102**. The patterning is carried out by forming an etching mask on the wiring electrode layer **103** and the vibration plate **106** followed by removal of the vibration plate **106**, except for the portion corresponding to the etching mask by etching. The etching mask is formed by coating a photosensitive resist onto the wiring electrode layer **103** and the vibration plate **106**, followed by pre-baking, and then a mask formed in a desired pattern is used for an exposure, development and treatment are performed, followed by post-baking.

FIG. **10** shows a protective layer **110** formed on the vibration plate **106**, the wiring electrodes **103**, and the shared electrode **107** and the insulating film **109**. The protective layer **110** is made of polyimide, and in the embodiment has a layer thickness of 3 μm. The protective layer **110** is formed from a solution containing a polyimide precursor and coated onto vibration plate **106** using a spin coating method. By spin coating, the protective layer **110** is formed to cover the actuators **102**, the wiring electrodes **103** and the shared electrode **107** formed on the vibration plate **106**, and to be a layer formed with a smooth surface. By patterning and etching, a circular pattern shape with, in the embodiment, a diameter of 20 μm is formed for the nozzle **101**, and a square cross section linear shape is formed for the wiring electrode terminal section **104** and the shared electrode terminal section **105** shown in FIG. **3**.

The nozzles **101** for ejecting the ink in the ink jet head **1** are formed through the protective layer **110** as seen in FIG. **10**. As the nozzle form is etched through the protective layer, in an aperture within the electrode and piezoelectric region at the center of the circular piezoelectric later **108**, a thin wall of the material forming the protective layer **110** lines the wall of nozzle **101**. The hole through the circular form of the piezoelectric layer has a 26-μm-diameter, formed to surround the circular pattern of the 20 μm nozzle **101** opening.

The inner wall of the 26-μm-diameter circular pattern arranged on the vibration plate **106** and the surface of the wiring electrode **103** are covered by the protective layer **110**. Of necessity, the portion of the protective layer **110** corresponding to the wiring electrode terminal section is removed. In the protective layer **110** that covers the inner wall of the circular pattern and the wiring electrode **103**, the ink-ejecting nozzle **101** opening communicating with the ink pressure chamber is formed.

When the actuators **102** are formed during the two rounds of patterning the vibration plate **106** and the protective layer **110**, due to unevenness in the etching process and limits in the precision of the photomask pattern, the nozzle diameters and the center position of the nozzles in the vibration plate **106** and the protective layer **110** may be different from each other, and the shapes and performance of the individual nozzles of the ink jet head **1** are thus different such that the accuracy of an ink droplet landing in the target position will suffer. However, according to the present embodiment, formation of the actuators **102** is carried out, by virtue of forming an enlarged hole through the piezoelectric layer and filling it with the protective layer material before forming the nozzle **101**, only by patterning and etching through the protective layer **110** in the hole so that an improvement in the accuracy and repeatability of the nozzle shape is possible, and an improvement in the accuracy of the position of the ink droplets to meet the desired target position among the plural nozzles is also possible.

The patterning method for the protective layer **110** when non-photosensitive polyimide is used is different from the patterning method when photosensitive polyimide is used.

When the non-photosensitive polyimide is in use (in this application example, Semicofine manufactured by Toray Industries, Inc., is used), after a solution containing the polyimide precursor is used to form a layer according to the spin coating method, baking is carried out for thermal polymerization and removal of the solvent followed by sintering. Then, an etching mask is formed on the non-photosensitive polyimide layer, and the polyimide layer, except for the portion corresponding to the etching mask, is etched off. Here, the etching mask is formed by coating a photosensitive resist onto the non-photosensitive polyimide layer, followed by pre-baking, and then a mask formed in a desired pattern is used for an exposure, development and treatment are performed and, followed by post-baking.

When a photosensitive polyimide is used (according to this application example, Photoneece manufactured by Toray Industries, Inc., is used), after the layer is formed according to the spin coating method, pre-baking is carried out. Then, exposure is carried out using a mask for exposure; more specifically, a mask that opens (to let light pass) for the nozzles **101**, the wiring electrode terminal sections **104** and the shared electrode terminal sections **105** is used when a positive-type photosensitive polyimide is in use. Or, a mask that blocks light for the nozzles **101**, the wiring electrode terminal sections **104** and the shared electrode terminal sections **105** is used when a negative-type photosensitive polyimide is in use. Exposure is followed by the development and treatment, and then post-baking for selective reaction of the exposed versus unexposed regions is carried out.

In addition to polyimide, the protective layer **110** may also be made of other types of resin materials such as ABS (acrylonitrile butadiene styrene), polyacetal, polyamide, polycarbonate, polyether sulfone, and other plastic materials. Also, one may also use ceramic materials such as zirconia, silicon carbide, silicon nitride, barium titanate, and other nitrides and oxides. When insulation of the wiring electrodes **103** and the shared electrode **107** can be guaranteed, one may also use a metal material (alloy). Typical metal materials that may be used in this case include aluminum, SUS, titanium, etc. In addition, other layer-forming methods may also be used, such as CVD, vapor deposition, gold plating, etc. The layer thickness of the protective layer **110** is preferably in the range from 1 μm to 50 μm.

When the material for the protective layer **110** is selected, it is preferable that the Young's modulus of the protective layer **110** be significantly different from the Young's modulus of the material used for the vibration plate **106**; that is, the materials for the vibration plate **106** and the protective layer **110** should have significantly different Young's moduli. The quantity of deformation of the plate shape is affected by the Young's modulus and the plate thickness of the material for the plate. When the same force acts on the two different materials, the lower the Young's modulus of the vibration plate **106** or the thinner the vibration plate **106** thickness, the larger the deformation of the vibration plate **106**. In the embodiment, the Young's modulus of the $SiO_2$ layer for the vibration plate **106** is 80.6 GPa, and the Young's modulus of the polyimide layer of the protective layer **110** is 10.9 GPa. The difference between their Young's moduli is 69.7 GPa. The following is an explanation of the reason to provide this difference.

According to this embodiment, the ink jet head **1** has a configuration in which the actuator **102** is located on the body of the vibration plate **106** (the actuator **102** is formed thereon) having the protective layer **110** coated thereover. When an electric field is applied to the actuator **102** so that the actuator **102** stretches in the direction orthogonal to the electric field direction, a force is created on the vibration plate **106** to deform the vibration plate into a concave shape on the side thereof facing the ink pressure chamber **201** side. In contrast, the force causes the protective layer **110** thereon to be deformed into a convex shape on the side facing away from the ink pressure chamber **201**. When the actuator **102** contracts in the direction orthogonal to the electric field direction by reversing the bias on the piezoelectric layer **108**, a force is applied so that the vibration plate **106** is deformed into a convex shape on the side thereof facing the ink pressure chamber **201**, and the protective layer **110** is deformed into a concave shape. That is, as the actuator **102** stretches/contracts in the direction orthogonal to the electric field direction, forces are applied to the vibration plate **106** and the protective layer **110** so that they are in opposite directions. Consequently, if the vibration plate **106** and the protective layer **110** have the same layer thickness and the same Young's modulus, even when a voltage is applied to the actuator **102**, because the forces that are applied to the vibration plate **106** and the protective layer **110** cause deformation of the same magnitude but in opposite directions, there is no deformation for the nozzle plate **100**, and no ink is ejected.

According to the present embodiment, when the protective layer **110** is a polyimide layer, because the Young's modulus of the protective layer **110** is lower than the Young's modulus of the $SiO_2$ layer of the vibration plate **106**, under the same force, the magnitude of the deformation of the protective layer **110** is larger. According to the configuration of the present embodiment, when the actuator **102** stretches in the direction orthogonal to the electric field direction, the nozzle plate **100** is deformed into a convex shape with respect to the ink pressure chamber **201** side so that the volume of the ink pressure chamber **201** becomes smaller (because the magnitude of the deformation when the protective layer **110** is deformed into a convex shape with respect to the ink pressure chamber **201** side is larger). In contrast, when the actuator **102** contracts in the direction orthogonal to the electric field direction, the nozzle plate **100** is deformed into a concave shape with respect to the ink pressure chamber **201** side, and the volume of the ink pressure chamber **201** becomes larger (because the magnitude of the deformation when the protective layer **110** is deformed into a concave shape with respect to the ink pressure chamber **201** side is larger).

When the same voltage is applied to the actuator, the larger the difference between the Young's moduli of the vibration plate **106** and the protective layer **110**, the larger the difference in the magnitude of the deformation of the vibration plate. Consequently, when the difference between the Young's moduli of the vibration plate **106** and the protective layer **110** is larger, it is possible to eject the ink at a lower voltage.

In addition, as explained above, the magnitude of the deformation of the plate shape depends not only on the Young's modulus of the plate material but also on the plate thickness.

Consequently, when increasing a difference in the magnitude of the deformation between the vibration plate **106** and the protective layer **110**, in addition to the Young's moduli of the materials, respective layer thicknesses also should be taken into consideration. Even when the material of the vibration plate **106** and the material of the protective layer **110** have the same Young's modulus, if there is a difference in the layer thickness, then ink can still be ejected, but the required voltage to eject the same volume of ink is higher.

In addition, when the material of the protective layer **110** is selected, consideration is also made for its heat resistance, the insulating properties (in consideration of the influence of the denaturing of the ink due to driving by the actuators **102** when an ink with a high electroconductivity is in use), the thermal expansion coefficient, the smoothness, and its wettability to the ink.

As shown in FIG. **11**, a protective layer cover tape **112** is applied to the protective layer **110**, and the ink pressure chamber structural body **200** is flipped so that the ink pressure chamber **201** formed in the ink pressure chamber structural body **200** is shown. Here, the ink pressure chamber **201** has a cylindrical shape with a diameter, in the embodiment, of 240 μm, and patterning is carried out so that the center of the ink pressure chamber **201** and the center of the nozzle **101** are aligned, or nearly aligned, with each other. This chamber structural body **200** with the actuator **102** formed thereon is flipped with respect to FIG. **10**.

In the following, the method for patterning the ink pressure chamber will be explained. The protective layer cover tape **112** is applied to the protective layer **110** shown in FIG. **11**. Here, the protective layer cover tape **112** is a back-surface protective layer for protection of the back surface during polishing (chemical mechanical polishing, CMP, of the silicon wafer).

An etching mask is formed on the ink pressure chamber structural body **200** made of a 725-μm-thick silicon wafer, and, as described in the patent application WO2003/030239 filed by Sumitomo Precision Industrial Co., Ltd., the anisotropic dry etching process technology known as Deep-RIE is used to remove the silicon in locations which are not masked by the etching mask portion to form the ink pressure chamber **201**. Here, the etching mask is formed by coating a photosensitive resist onto the ink pressure chamber structural body **200**, followed by pre-baking, and then a mask with a desired pattern formed on it is used for an exposure, development and treatment are performed, followed by post-baking.

For the Deep-RIE used solely for the silicon substrate, the SF6 is used as the etching gas. However, the SF6 gas is selective, as it does not exhibit an etching effect on the $SiO_2$ layer of the vibration plate **106** and the polyimide layer of the protective layer **110**. Consequently, the progress of the dry etching of the silicon that forms the ink pressure chamber **201** stops at the vibration plate **106**. That is, the $SiO_2$ layer of the vibration plate **106** plays the role of the etch stop layer for the RIE etching operation.

In the above explanation, one may also appropriately select from the wet etching method using a chemical solution and the dry etching method using plasma to form the ink pressure chamber **201** in the silicon wafer. Depending on the materials of the insulating layer, the electrode layer, the piezoelectric layer, etc., the etching method and the etching conditions may need to be changed to carry out the processing using a different etchant/process. After the end of the etching processing using each photosensitive resist layer, the residual photosensitive resist layer is removed using a dissolving solution. FIG. **12** shows the cross-section of the structure where the separation plate **300** and the ink-feeding path structural body **400** are bonded to the ink pressure chamber structural body **200**. Here, an epoxy resin adhesive is used for bonding. After the separation plate **300** and the ink-feeding path structural body **400** are bonded together, the separation plate **300** is bonded to the ink pressure chamber structural body **200**.

According to the present embodiment, the nozzle plate **100** is composed of the vibration plate **106**, shared electrode **107**, the wiring electrode **103**, the piezoelectric layer **108**, and the passivation film **110**, all of which are formed on the ink pressure chamber structural body **200**. Instead of the method in which the nozzle plate **100** is affixed to the ink pressure chamber structural body **200**, one surface of the ink pressure chamber structural body **200** is formed as the vibration plate. On one surface of the ink pressure chamber structural body **200**, the electrodes and the piezoelectric layer are formed. From the other surface side, a hole that does not go through the ink pressure chamber structural body **200** is formed at the position corresponding to the ink pressure chamber. On the one side of the ink pressure chamber structural body **200**, a thin layer is left, and this portion functions as the vibration plate. With this forming method, it is possible to use a portion of the ink pressure chamber structural body **200** as the nozzle plate **100** without using the nozzle plate **100**.

FIG. **13** shows the cross-section of the structure where an electrode terminal section cover tape **113** is bonded to the wiring electrode terminal section **104** of the protective layer **110**. Here, by irradiating UV light from the protective layer cover tape **112** side shown in FIG. **12**, the bonding strength of the protective layer cover tape **112** is decreased for separation. Then, as shown in FIG. **3**, in the region of the wiring electrode terminal section **104** and the shared electrode terminal section **105**, the electrode terminal section cover tape **113** is applied. This cover tape is made of a resin, and the bonding strength is equal to cellophane tape, which allows easy removal. The electrode terminal section cover tape **113** is bonded to prevent dirt from sticking to the wiring electrode terminal section **104** and the shared electrode terminal section **105** and to prevent the attachment of an ink-repulsive layer **114** when the ink-repulsive layer **114** is formed as to be explained later.

FIG. **14** shows a cross-section of the structure where the ink-repulsive layer **114** is formed on the protective layer **110**, except for on a portion of the inner wall of the nozzles **101**. Examples of the materials of the ink-repulsive layer **114** include silicone base liquid-repulsive materials having liquid-repulsive property and fluorine-containing organic materials. In the present embodiment, Cytop manufactured by Asahi Glass Co., Ltd., a commercially available fluorine-containing organic material, is used. In the embodiment, the layer thickness of the ink-repulsive layer **114** is 1 μm.

The ink-repulsive layer **114** is formed by spin coating a liquid ink-repulsive layer material onto the protective layer **110**. When the spin coating is carried out together with anchoring of the ink jet head **1**, positively pressurized air is injected through the ink-feeding port **401**. As a result, the positively pressurized air is exhausted from the nozzles **101** connected to the ink-feeding port **401**. In this state, as the liquid ink-repulsive layer material is applied, the ink-repulsive layer **114** is formed only on the protective layer **110** without attaching the ink-repulsive layer material onto the ink-flow channel of the inner wall of the nozzles **101**.

FIG. **15** shows the cross-section of a finished or complete ink jet head **1**. The ink is fed from the ink-feeding port **401** arranged in the ink-feeding path structural body **400** to the ink-feeding path **402**. The ink in the ink-feeding path flows through ink throttles **301** to the various ink pressure chambers **201** to fill the pressure chambers **201** of the respective nozzles

101. The ink fed from the ink-feeding port **401** is maintained at an appropriate negative pressure so that the ink in the nozzles **101** is held without leaking from the nozzles **101**.

FIG. **16** is a cross-sectional view taken across the B-B' axis of FIG. **3** of the wiring electrode terminal section **104** and the shared electrode terminal section **105**. The protective layer **110** is etched only to correspond to the wiring electrode terminal section **104** and the shared electrode terminal section **105**, and the ink-repulsive layer **114** is not formed on the protective layer **110**.

FIG. **17** is a cross-sectional view taken across the C—C' axis in FIG. **3** of the wiring electrodes **103** and the shared electrode terminal section **105**. FIG. **17** differs from FIG. **8** in that the protective layer **110** is formed on the wiring, and the ink-repulsive layer **114** is also formed on the protective layer **110**.

(Second Embodiment)

FIG. **18** is a diagram illustrating the ink jet head **1** in a second embodiment. This embodiment differs from the first embodiment in the shape of the actuators **102**. Otherwise, the configuration is the same.

The actuators **102** are in a rectangular shape. In the embodiment, each of the actuators **102** has a rectangular shape with a width of 170 μm and a length of 340 μm. The diameter of the nozzles **101** is 20 μm. The shape of the ink pressure chamber **201** is fitted to the shape of the piezoelectric layer **108**, and the ink pressure chamber **201** also has a rectangular shape.

In contrast to the circular piezoelectric layer pattern, the actuators **102** each have a size of 340 μm in the longitudinal direction. Consequently, the actuators for ejecting the ink are larger. As a result, it is possible to have a higher pressure for ejecting the ink.

(Third Embodiment)

FIG. **19** is a diagram illustrating the ink jet head **1** in a third embodiment. This embodiment differs from the first embodiment in the shape of the actuators **102**. Otherwise, the configuration is the same.

The actuators **102** are in a rhomboid (parallelepiped) shape. In the embodiment, each of the actuators **102** has a rhomboid shape with a width of 170 μm and a length of 340 μm. The diameter of the nozzles **101** is 20 μm. The shape of the ink pressure chamber **201** is fitted to the shape of the actuators **102**, and the ink pressure chamber **201** also has a rhomboid shape.

In contrast to the circular piezoelectric layer pattern of the first embodiment, the piezoelectric pattern can be more closely packed to provide a higher density of nozzles.

(Fourth Embodiment)

FIG. **20** is an oblique exploded view illustrating the ink jet head **1** in a fourth embodiment. This embodiment differs from the first embodiment in that the actuators **102** are offset from, i.e., do not overlie, the nozzles **101**. The center of a nozzle **101** is at a position offset from the center of the circular cross-section of one ink pressure chamber **201** corresponding thereto. The ink pressure chamber **201** overlies both the actuator **102** and the nozzle **101**. Other than the nozzles **101** being positioned offset from the position of the actuators **102**, this embodiment is the same as the first embodiment.

FIG. **21** differs from FIG. **20** in that the circulating ink-feeding port **403** and the circulating ink-exhausting port **404** are arranged near the two ends of the ink-feeding path **402** so that the ink is circulated in the ink-feeding path **402**.

FIG. **22** is a plane view illustrating the nozzle plate **100** in the fourth embodiment as viewed from the ink-ejecting side. Here, the nozzles **101** extend through the nozzle plate **100**. The center of the corresponding nozzle **101** is position offset from the center of the circular cross-section of one ink pressure chamber **201**. The piezoelectric layer has, in this embodiment, a circular shape. The piezoelectric layer is located at a position different from the nozzle **101**, such that the nozzle **101** is fully offset from the position of the piezoelectric layer **108**. In the embodiment, the diameter of the circular piezoelectric layer is 170 μm. The center of the piezoelectric layer is at a position offset from the center of the circular cross-section of the ink pressure chamber **201** and a small space exists between the nozzle **101** and the closest surface of the piezoelectric layer **108**. According to this embodiment, the center of the piezoelectric layer is at a position offset from the center of the circular cross-section of the ink pressure chamber **201**. However, one may also use a scheme in which the center of the circular cross-section of the ink pressure chamber **201** and the center of the piezoelectric layer are at the same position.

FIG. **23** is a cross-sectional view taken across the F-F' axis shown in FIG. **22**. This view differs from the first embodiment shown in FIG. **15** in that no region free of the layer formed by circular-shaped patterning is formed for locating the nozzle at the center of the shared electrode **107** and the piezoelectric layer **108** or the wiring electrode **103** of the actuator **102** portion. Just as in the first embodiment, the nozzles **101** are formed on the protective layer **110**; that is, circular openings with a diameter of 26 μm are formed on the vibration plate **106** to surround the 20-μm-diameter circular pattern of the protective layer **110**. The manufacturing process in the fourth embodiment is the same as that in the first embodiment other than the patterning shape which is different.

FIG. **24** is a cross-sectional view of the actuator **102** portion taken across the G-G' axis in FIG. **22**. It differs from FIG. **22** for the cross-sectional view taken across the F-F' axis shown in FIG. **22** in that the insulating layer **109** is between the actuator **102** and the shared electrode **107** at the site corresponding to H in FIG. **22**.

According to the first embodiment, there should be a circular patterning operation to form the nozzle at the center of the shared electrode **107**, the piezoelectric layer **108** and the wiring electrodes **103** of the actuator **102** portion. However, according to the fourth embodiment, such a circular patterning operation is not needed. Consequently, it is possible to avoid the tolerance issues in the positioning of the nozzle within the aperture in the piezoelectric layer. As a result, compared with the first embodiment, in this embodiment yield issues related to the ink ejection repeatability of the ink jet head **1** can be improved.

(Fifth Embodiment)

FIG. **25** is an oblique exploded view illustrating the ink jet head **1** in a fifth embodiment. This embodiment differs from the fourth embodiment in the shapes of the ink pressure chambers **201** and the actuators **102**. Otherwise, the configuration is the same.

The ink pressure chambers **201** and the actuators **102** are in a rhomboid shape. In this embodiment the actuators **102** are in a rhomboid (parallelepiped) shape with a width of 170 μm and length of 340 μm. The diameter of the nozzles **101** is 20 μm, and the actuators **102** and the nozzles **101** are at positions different from each other. Each ink pressure chamber **201** surrounds the actuator **102** and the nozzle **101**.

Compared with the circular piezoelectric layer pattern, the piezoelectric pattern can be arranged at a higher density.

FIG. **26** differs from FIG. **25** in that the circulating ink-feeding port **403** and the circulating ink-exhausting port **404** are arranged near the two ends of the ink-feeding path **402** so that the ink is circulated in the ink-feeding path **402**.

(Sixth Embodiment)

FIG. **27** is an oblique exploded view of the ink jet head **1** in a sixth embodiment. This embodiment differs from the fourth embodiment in the shapes of the ink pressure chambers **201** and the actuators **102**. Otherwise, the configuration is the same.

The ink pressure chambers **201** and the actuators **102** are in a rectangular shape. In this embodiment, the actuators **102** each have a rectangular shape with a width of 250 μm and a length of 220 μm. The diameter of the nozzles **101** is 20 μm, and the actuators **102** and the nozzles **102** are at positions different from each other. The ink pressure chamber **201** surrounds the actuator **102** and the nozzle **101**.

Compared with the circular piezoelectric layer pattern, the actuators **102** have a larger area, so that a higher ink ejecting pressure is possible.

FIG. **28** differs from FIG. **27** in that the circulating ink-feeding port **403** and the circulating ink-exhausting port **404** are arranged near the two ends of the ink-feeding path **402** so that the ink is circulated in the ink-feeding path **402**.

While certain embodiments have been described, these embodiments have been presented by way of example only and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions, and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

What is claimed is:

**1**. An ink jet head comprising a plurality of individual ink integrally formed jetting heads, each ink jetting head comprising:

a vibration plate having a first and a second surface and an opening of a first diameter extending therethrough from the first to the second surface;

an ink pressure chamber, communicating with the opening and arranged on the first surface of the vibration plate;

a first electrode formed on the second surface of the vibration plate;

a piezoelectric layer formed on the first electrode in a region adjacent to the opening, and that, in response to a driving voltage, deforms the vibration plate to expand or contract the volume of the ink pressure chamber;

a second electrode formed on the piezoelectric layer;

a protective layer which is at least formed on the vibration plate and the second electrode and lining the opening to form a nozzle for ejecting the ink having a diameter smaller than the first diameter; and

an ink-feeding supply fluidly coupled to the ink pressure chamber.

**2**. The ink jet head of claim **1**, wherein the vibration plate is a single unitary layer common to each of the jetting heads.

**3**. The ink jet head of claim **2**, wherein one of the first and the second electrodes of each ink jetting head are electrically interconnected to a common bus.

**4**. The ink jet head of claim **3**, wherein one of the first and the second electrodes of each ink jetting head is electrically connected to an independent contact pad.

**5**. The ink jet head of claim **1**, wherein the piezoelectric layer surrounds the nozzle opening.

**6**. The ink jet head of claim **5**, wherein the nozzle is formed to overlie a central position of the ink pressure chamber.

**7**. The ink jet head of claim **1**, wherein the piezoelectric layer is offset to the side of the nozzle.

**8**. The ink jet head according to claim **7**, wherein the Young's modulus of the material of the vibration plate is different from the Young's modulus of the material of the protective layer.

**9**. The ink jet head of claim **8**, wherein the vibration plate is comprised of an insulating material.

**10**. The ink jet head of claim **1**, wherein the protective layer is comprised of a resin material.

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